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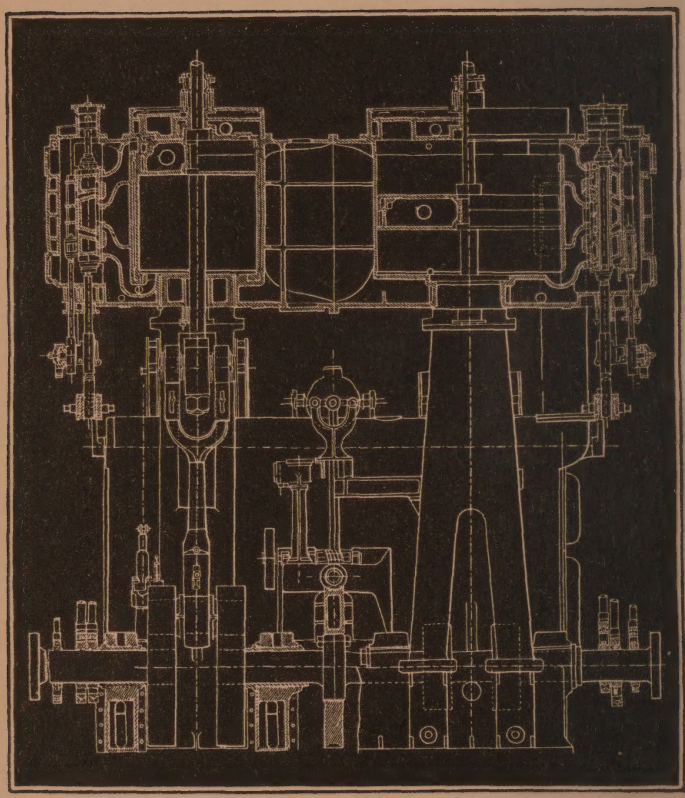

ENGINES OF THE STEAMSHIPS

"PENNSYLVANIA," "OHIO," "INDIANA," AND "ILLINOIS," OF THE

AMERICAN STEAMSHIP CO.

A CATECHISM

OF THE

MARINE STEAM ENGINE,

FOR THE USE OF

ENGINEERS, FIREMEN, AND MECHANICS.

A PRACTICAL WORK FOR PRACTICAL MEN.

BY EMORY EDWARDS,

MECHANICAL ENGINEER.

ILLUSTRATED BY SIXTY ENGRAVINGS,

INCLUDING EXAMPLES OF THE MOST MODERN ENGINES.

PHILADELPHIA:
HENRY CAREY BAIRD & Co.,
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TO

MY BROTHER,

FREDERICK W. EDWARDS,

AT WHOSE SUGGESTION THESE PAGES WERE WRITTEN,

AND TO WHOM I AM INDEBTED

FOR MUCH VALUABLE ASSISTANCE

IN THEIR PREPARATION,

THIS BOOK IS DEDICATED BY

THE AUTHOR.

68060

PREFACE.

Should expert engineers say that they find nothing new or interesting to them, in these pages the author would remind them that it was not intended they should, as it was not written for them, but on the contrary, it is intended exclusively for young and inexperienced engineers, mechanics, and firemen, who wish to adopt Marine Engineering as a profession. It has been compiled by the author from an experience of 15 years in the management of marine engines at sea, both in the navy and the merchant service; consequently a knowledge has been acquired during that period of what is actually required to be known to become a good practical engineer.

Thus knowing what is needed, and also the great dislike of practical men for mathematical formulæ, he has written it in the simplest and plainest language, with no attempt at diction, so that any man or boy who can merely read, and understand what he reads, will understand it.

It contains all that is requisite without being encumbered with pages of useless matter or drawings of obsolete types of engines and boilers.

Should his brother engineers censure him for giving as it were the "secrets" of the business to the million, he would remind them that it is the *duty* of every man to do all the good he can to his fellowmen while living, so that when he shall have passed away, the world may be all the better for his having lived in it; and, if he shall have smoothed the way for others over which he has so painfully trod, if he shall enable one worthy man or boy to better his condition in life, if he shall, as it were, "cause two blades of grass to grow where one only grew before," his only object in writing it will be fully accomplished.

The examples of English naval marine engines in chapter 41 are taken from "The Report on European Ships-of-War" etc., by Chief-Engineer J. W. King, U. S. N., other engines from *Engineering*, and the American engines generally from the *Scientific American*, to each of whom credit is hereby gladly given.

He will say in conclusion that these pages have generally been written at night after the labors of the day, and, taken as a whole, they are the product of a weary hand, and an overtasked brain; he therefore asks the generous indulgence of the reader for any errors or inaccuracies that may have unavoidably crept in.

EMORY EDWARDS, M. E.

U. S. S. "Rose," April 5th, 1879.

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INTRODUCTION.

QUALIFICATIONS FOR ENGINEERS.

Ques. What qualifications are necessary for a marine engineer.

Ans. The very first qualification is *sobriety*. No man who drinks intoxicating liquors to excess is fit to be an engineer, fireman, or in fact anything else on board a steamer, and the law should be so amended as to prohibit, under the severest penalties, the employment of such men. A drunken engineer or pilot may not only destroy himself, but hundreds of innocent men, women, and children who have entrusted their lives to his care.

Ques. Should not an engineer be a machinist by trade.

Ans. Not necessarily so, but he should be a man of "mechanical ideas." Practical marine engineering consists in the *tact* of the engineer in discovering faults in the working of his engine, and in applying the proper remedy. A marine engineer must be something of a machinist, boiler-maker, copper-smith, and steam-fitter, and he can learn all this on board ship.

A man might be a good machinist but a poor engineer for want of *tact.*

Ques. What course should a man pursue to become a good practical marine engineer?

Ans. Go into the fire room as a fireman, and by attention to duty, industry, and by general good conduct, work his way up. He must keep his eyes and his ears open, and learn something every day. When machinists, boiler-makers, copper-smiths, or steam-fitters come on board to make repairs, watch them and see how they make them, and thereby learn how to make them himself. He should visit all the machine shops he can, and also other steamers, so as to become familiar with the mode of construction, and different types of engines and boilers. He should not be either ashamed or afraid to ask for information about anything he does not *thoroughly* understand. He should not play the "smart-Alec," pretending to know a great deal more than he really does, for "there is more hope for a fool than such a man." True merit is always modest. And last, but not least, he should keep himself read-up in his business. Marine engineering is progressive, and he must keep himself posted on the improvements of the day by reading all books and papers relating to the profession, and not trust to his own experience, which is necessarily limited, alone.

Ques. What American papers would you recommend.

Ans. Scientific American; American Machinist; The American Ship; Manufacturer and Builder; Scientific News, and others, all of which contain much valuable information.

Ques. Does not a great deal depend on the chief engineer?

Ans. It does, and if the chief takes an interest (as he should) in his assistants and men, and they have a *desire* to learn, there will be no difficulty in their rising in the profession.

CATECHISM

OF

THE MARINE STEAM ENGINE.

CHAPTER I.

STEAM.

Ques. What is steam?

Ans. Steam is an elastic, invisible fluid generated by the application of heat to water.

Ques. What is a steam engine?

Ans. An engine moved by steam.

Ques. How many kinds of steam engines are there?

Ans. All steam engines are divided into two great classes—high-pressure, or non-condensing engines, and low-pressure, or condensing engines. Of each of these two classes there are many varieties. All locomotives, and most of the engines used on land, are non-condensing engines. While all marine engines, with the exception of those of the smaller class of tug-boats, and Western river steamers are condensing engines. The terms condensing and non-condensing should be used instead of high-pressure and low-pressure. Many steam vessels

now carry 60, 80, and even 100 pounds pressure of steam, and therefore the term low-pressure is no longer applicable.

Ques. What kind of engines are used on sidewheel steamers?

Ans. In this country the walking-beam engine is in universal use, except on the Western rivers, though occasionally you will find an engine of the "inclined," or the "cross-head" type. The walking-beam engine will be the standard engine in the future, as it has been in the past, for sidewheel steamers, and therefore my remarks on sidewheel engines will chiefly refer to that type.

Ques. What type of engine is most generally used on screw steamers?

Ans. The kind known as the vertical inverted cylinder engine, in which the cylinder stands vertically over the shaft. They are generally put up in this way, whether simple or compound.

Ques. Will you please explain the construction and management of marine engines and boilers?

Ans. Suppose we begin with the boiler first, and after we have exhausted that subject, we will take up the engine. So you can now go ahead with your questions on the boiler, and I will endeavor, by using the simplest language possible, to give you all the information necessary to enable you to become a good, practical marine engineer.

CHAPTER II.

BOILERS.

Ques. What kind of boilers are used in steam-vessels?

Ans. There are three kinds or types in general use, and when of good design, well made, and of good material, they all give satisfaction. The great fault of most boilers in steam-vessels, is contracted water-space and steam-room, which is the principal cause of their foaming. Fig. 1 is a flue boiler.

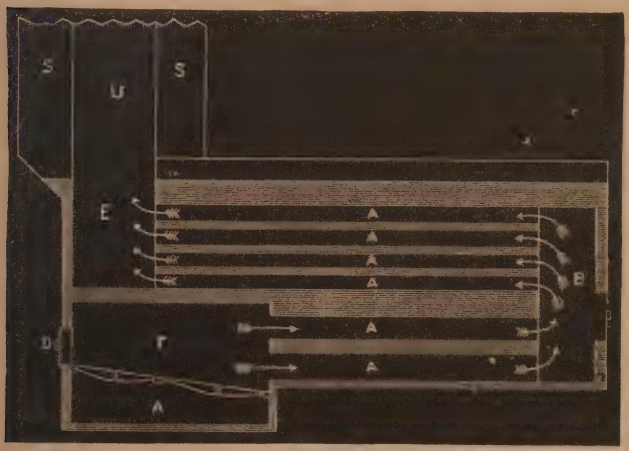


Fig. 1.

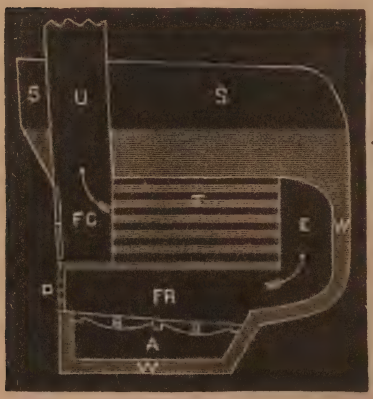
F—Furnace; *A*—Ash-pan; *G*—Grate-bars; *B*—Back connections; *D*—Furnace door; *E*—Front connections; *U*—Uptake; *S*—Steam-chimney.

Arrows show direction of smoke to smoke-stack; shaded portion shows water-space.

Boilers of this type occupy much room in a vessel, but they are easily kept clean and free from scale, as a man can get at all parts of the interior of them to scale them; they are the best kind to use with a low-pressure of steam (not exceeding 40 lbs.) and a *jet* condenser if the vessel runs in salt water.

Ques. What is a tubular boiler?

Ans. Fig. 2 is a tubular boiler, or fire-tube



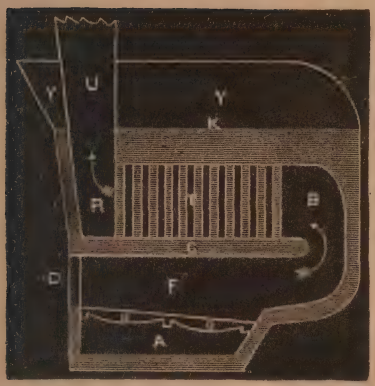
Fire-tube boiler, showing *fire* within the tubes; shaded parts show water-space.

S—Steam room; *U*—Uptake; *T*—Tubes; *E*—Back connections; *FC*—Front connections; *FR*—Furnace; *B*—Grate-bars; *A*—Ash-pan; *W*—Water-legs; *D*—Furnace door.

Fig. 2.

boiler—as they are generally called—with the *fire* passing through the inside of tubes. Whereas, in the water-tube boiler, Fig. 3, the reverse is the case. In this boiler the *water* is on the inside of the tubes, and the fire on the outside.

Fig. 4 shows a fire-tube boiler, with a cylindrical shell, with furnace placed within large flues. This kind is now used on all great ocean steam-



F—Furnace; *G*—Grate-bars; *A*—Ashpan; *B*—Back connections; *T*—tubes; *Y*—Steam space; *C*—Water level; *R*—Front connections; *D*—Furnace door; *C*—Crown-sheet.

Water-tube boiler. Shaded portion shows water-space with the *water* in the tubes.

Fig. 3.

ers, running between this country and Europe, as well as in the U. S. Navy. It is a strong boiler, steams well, is easily kept clean; and bids fair to drive all others out of the market.

F—Furnace; *R*—Grate bars; *A*—Ash-pan; *S*—Shell; *T*—Tubes; *M*—Manholes; *C*—Steam chimney; *U*—Uptake.

Fig. 4.

Ques. What kind of a marine boiler would you consider a good one?

Ans. One that was large enough to make plenty of steam, with a natural draft, without forcing the fires. I believe in plenty of boiler power. A large boiler may cost more to build, but it will be cheaper in the end, as it will last longer, and steam better with less coal. It should be made of the very best material, double riveted, and to stand *double* the working pressure.

Ques. Of what kind of iron should boilers be made?

Ans. The best charcoal iron; no puddled iron should be accepted.

Ques. Is not steel coming into use as a material for boilers?

Ans. I do not know of any boilers, of large size, made entirely of steel, but it is very common to make the crown-sheet, steam-chimney, and corners of water-legs of steel, and it gives great satisfaction. Steel answers well with new iron, but it "don't pay" to repair old boilers with it, as it is difficult to make the seams tight, owing to the metals not expanding and contracting equally.

Ques. Will you give me the proper thickness of the iron entering into the construction of a boiler.

Ans. Shell, 5-16; water-legs, 5-16; crown-

sheet, 3-8; tube-sheet, 1-2; steam-chimney, 5-16.

Ques. What size and kind of tubes are mostly used?

Ans. Three-inch lap-welded tubes of any length required, but seldom more than 7 feet long, and 1-8 inch thick. Composition tubes are sometimes used, but they are no better, if as good as iron, and cost more.

Ques. Should not every steamer carry some extra tubes of proper length?

Ans. Yes, and also one of Prosser's tube expanders, and then the engineer can cut out the old, leaky, plugged-up tubes, and put in new ones himself.

Ques. What other extra material should be carried for repairs to boilers?

Ans. A sheet of boiler-iron for patches, some rivets for hard patches, and some bolts, nuts, and washers for soft patches, red lead (dry), white lead, and iron borings for cement, and last, but not least, a dozen or more wrought iron gas plugs of different sizes.

Ques. How and of what material are marine boilers generelly constructed?

Ans. All steam boilers are constructed of iron, or steel plates, of varying thickness (according to design, and the pressure they are intended to bear), and are riveted together. The rivets are generally 11-16 inch in diameter,

and spaced 1 7-8 inches from centre to centre. After the plates are riveted together, they are chipped to an edge, and made steam and water tight, by caulking them with a flat-pointed chisel, called a caulking-tool. The interior of the boiler is strengthened to withstand the pressure, by iron braces, stay-bolts, and socket-bolts. A great deal of ignorance is often displayed in the design and proportions of these braces, especially in their attachment to the shell. Boiler-making does not receive the attention from scientific men which its importance demands, and until it does, there will be but little improvement in design or construction.

Ques. Will you name some of the defects in the construction of boilers, and suggest some improvements?

Ans. The prevailing fault in boiler-making, or "sledge hammer engineering," as it has been aptly termed, is in *punching* the holes in the plates, instead of *drilling* them; and in heading the rivets by hand, instead of by machine. The difference in the strength between punched and drilled holes, is from ten to twenty per cent. in favor of the latter, and another great advantage in drilling holes, is this: in punching them, it is necessary to punch each plate separately, and with the greatest care and skill, it is impossible to get the holes to match

each other properly. They will overlap each other more or less, and then a "drift" (a tool which should be discarded in every boiler-shop) is brought into play to *force* them together. Machine riveting is superior to hand riveting, because the powerful pressure which is brought to bear on the rivet causes it to be pressed into all parts of the two holes, filling them completely, whereas, with hand-riveting, the holes are not filled, as it is impossible with the blows of a hammer to subject the rivet to so powerful or uniform a pressure, as the machine upon them. Fig. 5 shows two plates riveted by a machine, with the holes drilled; while Fig. 6 shows two plates with punched

Fig. 5.

Fig. 6.

holes, and hand-riveted. The superiority of the former over the latter can be seen at a glance. Another advantage would be to *plane* the seams to be caulked, instead of chipping them with a cold chisel after they are riveted together.

Still another improvement in boiler construc-

tion, would be to place the tubes somewhat zig-zag, instead of one above the other, as is the usual practice. By so doing, the steam could escape more easily from the surface, and the water would have a better circulation. Fig. 7 shows the tubes as generally arranged, while Fig. 8 shows the method suggested.

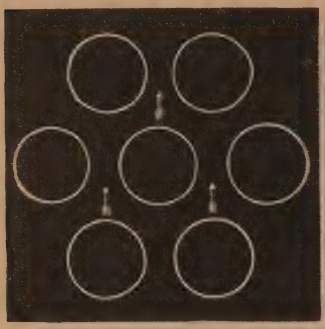


Fig. 8.

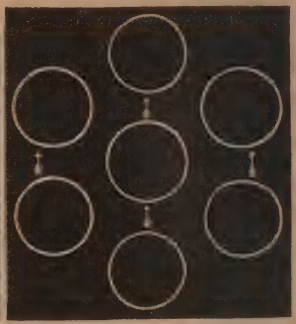


Fig. 7.

The weakness of boilers arises, generally, not from insufficient material, and perhaps not as often from inferior quality, as it does from the weakness of the attachments of the various parts. Unless there is some reason for a contrary opinion it may be assumed that riveted work will always be done badly. The chief defects of such work are out of sight, and to a great extent undiscoverable after it is finished. Mismatched and unfilled holes cannot be seen after the heads on the rivets are formed, and therefore such work is less subject to criticism and in-

spection, and, consequently, there is little rivalry or pride of excellence in doing it among mechanics. Without the very closest inspection it is always possible for a workman to hide his blunders and his carelessness. Then, too, there is no strong sense of the necessity of good work of this kind. There is generally a lack of what might be called mechanical moral sense in this respect; and an engineer who should insist upon having first-rate work would find it no easy task to have his orders executed.

CHAPTER III.

ATTACHMENTS TO BOILERS.

BLOW-COCKS.

Ques. What are blow-cocks?

Ans. Every boiler should have two blow-valves, one placed near the surface of the water, called the "surface-blow," and one placed near the bottom, called the "bottom-blow." The surface-blow is the smaller of the two, and is generally used for blowing out when freshening the water; the bottom-blow is mostly used when blowing out entirely for repairs, or cleaning out. Plug-cocks are sometimes used, but they are very inferior to globe-valves for that purpose, or indeed for any other.

STOP-VALVES.

Ques. What are stop-valves?

Ans. There should be a globe-valve on the main steam-pipe where it connects with the boiler; then should any accident happen to the engine, throttle-valve, or steam-pipe itself, the steam can be shut off and repairs made without blowing off the steam; whereas, without one, the engine and fire room might be filled with steam, driving everybody from his post, and causing destruction to life and property. Next to a good safety-valve, I consider a stop-valve the most important attachment to any boiler. There should also be a small globe valves, (no plug-cocks) of suitable sizes on *all* the pipes leading from the boiler, such as the steam-gauge-pipe, donkey steam-pipe, whistle-pipe, and others, except the pipe leading to the "locked" safety-valve. So that in case of accident the steam can be immediately shut off, and repairs made.

PIPES.

Ques. Of what metal are the different pipes made?

Ans. The main steam-pipe should be made of copper, 1-8 inch thick, and be fitted with a "slip-joint," so that it can expand and contract without causing the seams or joints to crack or leak; all feed and blow-pipes should also be of copper. The steam-gauge-pipes should be of brass, the glass water-gauge-pipe, the whistle-pipe, and donkey steam-pipes may be of wrought-iron.

CHECK-VALVES.

Ques. Where should the check-valves be placed?

There should be attached directly to the boiler a check-valve on every feed-pipe leading from the engine, donkey-pumps, or injector, and it should be kept ground in tight, as a leaky check-valve will often prevent a feed-pump from working.

CHAPTER IV.

SMOKE-STACKS.

Ques. Of what material are smoke-stacks made?

Ans. Smoke-stacks are generally made of sheet-iron, each sheet 3-16 inch thick, and about 9 feet in length.

WASTE STEAM-PIPES.

Ques. Should not the waste steam-pipe, leading from the safety-valve be carried up to the top of the smoke-stack?

Ans. It should, though it is seldom done, because wherever the waste steam strikes the stack it will wear it into holes.

BANDS.

Ques. How many bands should be on the smoke-stack to attach the guys to?

Ans. There should be two at least, so that if one should give way, the stack would still have one to support it.

SMOKE-STACK GUYS.

Ques. What about smoke-stack guys?

Ans. Smoke-stack guys require watching at sea; they should always be set taut, when the pipe is hot, otherwise the bands or hooks will be carried away or broken off by its expansion. Ropes should never be used for guys, but small chains or jointed rods.

BOILER FELTING.

Ques. Are not boilers, steam-pipes, etc., covered with felting to prevent radiation of heat?

Ans. Yes; and of the many kinds of felting in use the common hair felt, and the "Asbestos" felting are the most popular, and give great satisfaction. When felting is put on a boiler or pipe, it should not rest on the iron, but it should be so applied as to leave an *air space* between it and the metal. After it is on and secured in place, the felting on the boiler should be covered with thin sheet-lead (soldered at the joints) or galvanized sheet-iron to protect it from water dripping from the deck.

Ques. Do not some engineers whitewash their boiler felting?

Ans. They do, but it is a most objectionable practice. If you cannot afford sheet-lead or galvanized sheet-iron, use paraffine varnish (refined coal tar), put on *hot;* it is cheap, looks and wears well, and "sheds water like a

duck." The felting on steam-pipes should be covered with canvas, and painted. Proper thickness of felting for boilers, 1 1-2 inches; for steam-pipes, etc., 1 inch.

GRATE-BARS.

Ques. What are the proper length and size of grate-bars, and what kind are in general use?

Ans. Many kinds of "patent" grate-bars have been introduced, fairly tried, and abandoned, as none of them proved superior to the old-fashioned bar in general use; and I advise you to let them all alone. When the furnace is more than four (4) feet long, the bars should be put in in two lengths, but if it is four feet or less in length, one bar will suffice, in which case only two bearing bars will be required. When a centre bearing bar is used for two lengths, it should be made like a double grate-bar, that is, with an opening or air space in the middle. Grate-bars when hot, expand considerably, and therefore they should not be put in tight, or too close together, but should have both end and side play, otherwise they will bend and twist out of shape, and soon be destroyed. Every steamer should carry a dozen or more extra bars, both single and double, as they frequently and unexpectedly give out. The proper dimensions for a good bar, are as follows: 3-4 inch on face, 1-4 inch on lower edge, 5-8 inch air space.

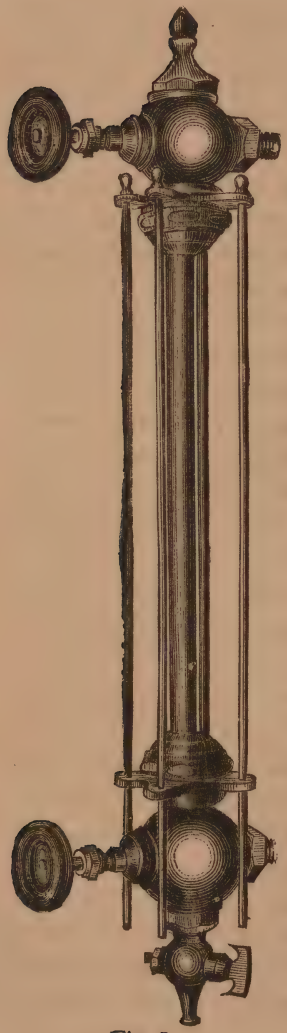


Fig. 9.

CHAPTER V.

GLASS GAUGES.

Ques *What are glass gauges?*

Ans. Glass gauges are simply thick glass tubes attached to the boiler for the purpose of showing the height of the water in the boiler, the same as gauge-cocks. They are more convenient than the gauge-cocks, as the height of the water can be seen at a glance. As these gauges are liable to get stopped up by mud or other impurities in the water, they should be blown through occasionally, to see that they are clear. The glass gauge should not be attached directly to the boiler, but to a pipe leading from the steam-chimney, down to the solid water below, over, or near the crown-

sheet. In this position it will not be affected by the foaming of the water When putting in a new glass tube, should it be too long, you can cut it off as much as required by merely scratching it on the *inside*, with a small round file. Any person who has never tried this method, will be surprised how quickly and nicely it can be done Little gum washers for packing the glass tube, can be had at all dealers in engineer's stores, or they can be made out of sheet gum Some engineers pack them with lampwick, bu⁴ I prefer the prepared gum washers As glass gauges are very liable to break, a number of extra ones should always be carried on board. The gauge here shown is furnished by W. C. Duyckinck, 50 John Street, New York.

GAUGE-COCKS.

Ques. What are gauge-cocks, and what are they used for?

Ans. Gauge-cocks are small plug-cocks, screwed into the boiler, to show the height of the water They are generally three in number, and placed one above the other, about 3 inches apart; the lower one should be fixed just above the level of the upper row of tubes, or back connection plate, and the water should *never* be allowed to get below it; if it does the tubes and connections will get overheated, and then should the feed-water be put on, an explosion would be the result.

LOW WATER.

Ques. But suppose, owing to the feed-pump not working, the boiler foaming, or any other cause, the water should fall below the lowest gauge-cock, what is to be done?

Ans. If the fires are light, and they can be hauled *quickly*, haul them, but should they be heavy, the better plan is to smother the fire with fresh coal, dust, or ashes out of the ash-pans; this will kill the fire for some time, and render it harmless. Do not attempt to put the fire out by throwing water into the furnace, or the steam will rush out and scald you to death. Do not raise the safety-valve, or open the stop-valve, or do anything that will lift the water up to the hot tubes or sheets; open the furnace door and connection doors, and let the boiler cool off; in an hour or so you can fill it up again with a hand pump. In some boilers, with contracted water and steam-room, the water will be lifted several inches above its true level, while the engine is in motion, and will fall as soon as the engine stops; thus, such a boiler might show six inches of water in the glass gauge, or gauge-cocks, while the engine was in motion, and yet drop entirely out of sight on stopping the engine: should this happen, you should start the engine again, or raise the safety-valve to lift the water, and keep it lifted while you pump more in. The first thing

to do in every case, when you stop the engine, is to see how the water stands in the boiler. Boilers addicted to foaming are dangerous, and need close watching.

Ques. Do boiler-makers always place the glass water-gauge, and gauge-cocks in their proper positions?

Ans. They should do so, but they often misplace them. When the top row of tubes and back connections are covered with water to the depth of 3 inches, the water should just be seen in the glass gauge, and show in the lowest gauge-cock, and it will if it be properly set. I once had charge of a boiler which showed four inches of water in the glass, when the upper row of tubes was bare, and another which had eight inches of water over the tubes, when the water could just be seen in the glass gauge. Now, the proper thing for every engineer to do on taking charge of an entirely new or strange boiler, is to fill the boiler (leaving the manhole open) so as to cover the top row of tubes or flues, and top of back connection, and then notice where it stands in the glass gauge and *mark* it; he can then always tell at a glance how the water stands in the boiler. No doubt a great many boiler explosions have resulted from this very cause of misplaced glass gauges, they showing plenty of water when the tubes were actually bare and red-hot.

CHAPTER VI.

HYDROMETER.

Ques. What is a hydrometer, and for what purpose is it used?

Ans. The hydrometer (Fig. 10) is an instrument used for the purpose of determining the specific gravities of liquids. When applied to the water of marine boilers, it indicates the amount of saline matter the water contains. The figure shows the kind of hydrometer usually used on board American steamers. The lower globe is filled with shot, to keep the instrument upright. When the hydrometer is placed in fresh water, the point, F. W., stands even with the surface of the water; when placed in water containing one pound of saline matter in thirty-two pounds of water, it stands at 1-32; when the water contains two pounds of saline matter in thirty-two pounds of water it stands at 2-32, and so on. So that by placing this instrument in a small quantity of water, drawn from the boilers at intervals, it will show the exact density, by which we know how to regulate the blowing-off.

Fig. 10.

In the boilers of sea-going vessels the water is usually from 1 3-4 to 2, per hydrometer.

Ques. How is a hydrometer used to tell the saltness of the water?

Ans. Attached to every boiler using sea-water, there is, or should be, a brass pot, called the salinometer pot (Fig. 12). Now, to test the water in the boiler, you open the cock on the salinometer, and fill it with water from the boiler, then place the thermometer (Fig. 11), one of the

Fig. 11.—Salinometer thermomter.

kind made for the purpose, and the hydrometer in the water. Both the thermometer and the hydrometer are marked 190°, 200°, and 210°, and in trying the water their temperatures should correspond. That is to say, if the thermometer shows 190°, look at the degree on the hydrometer, and likewise for 200°, and 210°; when filling the salinometer pot, the water should be allowed to run through for a few minutes, so as to get the water good and hot from the boiler, as well as to get rid of the water which was in the pipe.

Ques. At what point must the water be kept?

Ans. If the hydrometer stands at 2-32 or more than that, you must pump, and blow, and

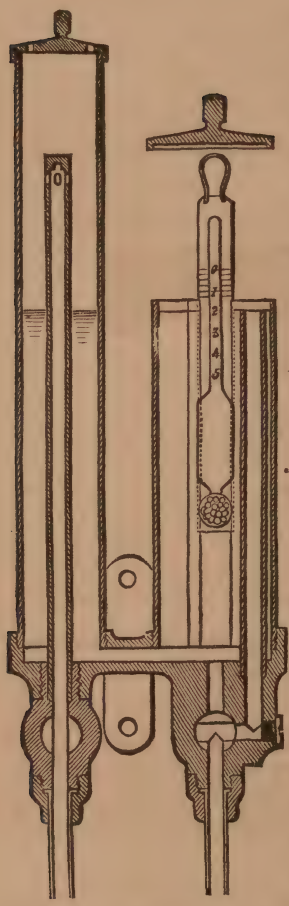


Fig. 12.—Salinometer Pot.

freshen the water. Don't "guess" when and how much to blow, or you may blow when there is no need for it, or not blow enough. Ten dollars will pay for a salinometer pot, with thermometer and hydrometer complete and ready for use, which is a trifling sum for so valuable an instrument. Unless the engine has a *surface* condenser, the pressure on the boiler should never exceed 40 pounds per square inch, as the sulphate of lime in the water is deposited at that pressure *without any concentration at all*, and, therefore, the more you would pump and blow, the more scale would be made. Hence the necessity for a surface condenser when the pressure of steam is 40 pounds or more, on boilers using sea-water. The instrument here shown is furnished by W. C. Duyckinck, 50 John Street, New York.

CHAPTER VII.

HOW TO SET A SAFETY-VALVE.

Ques. Will you inform me how to set a safety-valve?

Ans. As shown in the following figure:

Fig. 13.

Let P = Power.
W = Weight.
S = Short arm.
L = Long arm.

Then:

P × S ÷ L = W.
W × L ÷ S = P.
S × P ÷ W = L.
L × W ÷ P = S.

Short arm is the distance *A*—*B*.

Long arm is the distance *A*—*C*.

Power is area of valve, multiplied by steam-pressure.

Area of valve is found by multiplying the square of its diameter by the decimal .7854.

Example.—Suppose in the above figure we have the following dimensions:

Diameter of valve, 3 inches; pressure of steam, 20 pounds per square inch; length of short-arm (*a*—*b*), 3 inches; length of long arm (*a*—*c*), 30 inches. To find the required weight, we first find the power:

```
    3
    3
   ---
    9
  .7854
 ------
 7.0686  = Area of valve.
   20    = Pressure of steam.
------
141.3720 = Power.
```

Now, leaving out the fraction (.3720), we take the power, 141, and multiplying it by the short arm, 3, and divide by the long arm, 30, and we have 14 1-10 pounds as the proper weight of the ball to balance the pressure of 20 pounds per square inch. Thus:

$$
\begin{array}{r}
141 \\
\quad 3 \\
\hline
30)\overline{423}(14\tfrac{1}{10} \quad = \text{W.} \\
\quad 30 \\
\hline
\quad 123 \\
\quad 120 \\
\hline
\quad \tfrac{3}{30} = \tfrac{1}{10}
\end{array}
$$

Proof.

$$
\begin{array}{rcrcr}
141 & \times & 3 & = & 423. \\
14\tfrac{1}{10} & \times & 30 & = & 423.
\end{array}
$$

In the above the weight of the valve, stem, and lever is not included. The weight of these can be easily found by using a spring balance, lifting them from the point B. Suppose in the above case, the valve, stem, and lever weigh 4 pounds, we deduct that amount from the weight of the ball, which would leave 10 1-10 pounds, as the true weight of the ball. The engineer can set his safety-valve in a practical manner, by sliding the weight in or out on the lever, and *marking* it where the valve just begins to blow at different pressures.

PROPER LIFT OF A VALVE.

Ques. What is the proper lift of a valve?

Ans. The proper lift of any round or conical valve, be it a safety-valve, check-valve, or poppet-valve, is 1-4 of its diameter.

Thus a 4 inch valve has 1 inch lift.

2	"	"	"	1-2	"
1	"	"	"	1-4	"
5	"	"	"	1 1-4	"
6	"	"	"	1 1-2	"
8	"	"	"	2	"

Divide the diameter by 4, and the result will be the proper lift.

Ques. Are not safety-valves in which the valve is kept down by springs superior to those just described with lever and weight?

Ans. They are, as will be seen by the following official report of a board of naval engineers upon that subject.

"*ASHCROFT'S NICKEL-SEATED SAFETY-VALVE.*

"The most important attachment to a steam boiler is the safety-valve; if this is defective, or will not work properly, danger exists, and it should be remedied at once.

"Fig. 14 shows Ashcroft's Patent Nickel-Seated Safety-Valve, made by the Ashcroft Man'f'g Co., Boston, Mass., and which has achieved a very high reputation for reliability wherever it has been in use. It is perfectly automatic in its action, capable of discharging all the steam generated in a steam-boiler in excess of a given limit. Its bearing surfaces being made of nickel cannot corrode, thus rendering it always reliable. If desired, the valve may be locked up.

"There is but little doubt that whatever may be the primary cause of boiler explosions, the immediate cause is an excess of pressure,

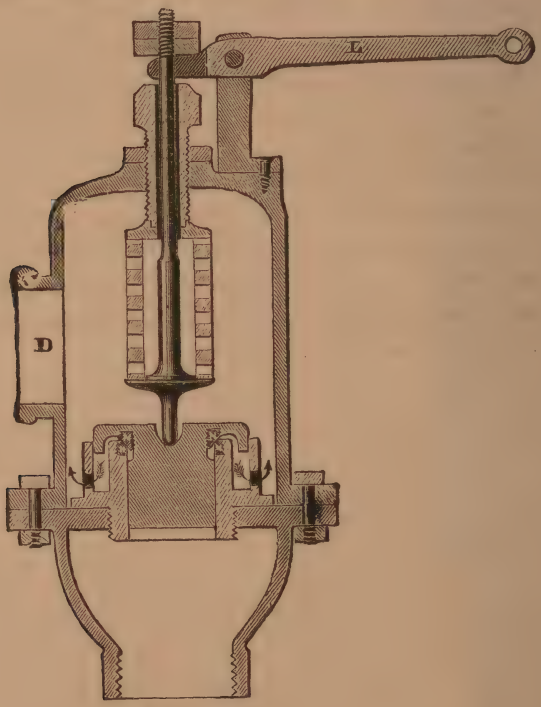


Fig. 14.

which an efficient safety-valve might be depended upon to relieve. In this connection we shall refer to the results of some extensive tests made by the 'United Railways of New Jersey,' at which the U. S. Government was

officially represented by a Board of Naval Engineers, detailed from the Navy Department. The following is a brief extract from their report:

"'That, with only a wood fire, generating a far less quantity of heat in equal time than a coal fire, there were required only thirteen minutes to raise the pressure from the inspector's working allowance of thirty pounds per square inch to the exploding pressure of fifty-three and one-half pounds per square inch; showing that a few minutes' absence or neglect of the engineer, coupled with an overloaded or inoperative safety-valve, are all that are needed to produce the most destructive steam boiler explosion, even with an old and unequally braced boiler, in which it might be supposed a rupture of the weakest part would precede other fractures, and allow the escape of the pressure without further injury.

"'That, in accounting for either the fact of an explosion, or for its destructive effects, there is no necessity for hypotheses of low water, enormous pressures, instantaneous generations of immense quantities of steam, superheated steam, the formation of hypothetical gases, development of electricity, etc. The most frightful catastrophe can be produced by simply gradually accumulating the pressure of saturated steam to a strain at which the

strength of the boiler yields; nor need that pressure be much above what is ordinarily employed with boilers of this type.

"'That this experiment has conclusively disposed of several theories of steam boiler explosion, replacing vague conjecture and crude hypothesis with exact experimental facts, and, by thus narrowing the field for the search of truth, has made the discovery more probable.'

"The ordinary safety-valve as now constructed consists of a disk which closes the outlet of a short pipe leading from the boiler. The real diameter of safety-valves must be greater than the theoretical orifices, because common observation shows that valves do not rise appreciably from their seats, and to make the outlet around the edges of the valve equal in area to the pipe, the valve should rise quarter of its diameter. On steam vessels, too great care cannot be taken with the safety-valves. We include herewith a report of Board of U. S. naval officers on Ashcroft's Patent Nickel-Seated Safety-Valve:

"'BOSTON, MASS., January 13, 1876.

"'*Engineer-in-chief*, W. W. H. WOOD, *U. S. Navy, Navy Department, Washington, D.C.*

"'SIR:—In obedience to the order of Navy Department, under date of December 14, 1875, the Board appointed to test the Patent Nickel-

Seated Safety-Valve, in comparison with those ordinarily used on the boilers of United States Naval vessels, met on the 12th inst., at Lynn, Massachusetts, and completed the trial of the same.

"'The valves of 2 1-2 inches diameter, were of the size most approximate to the dimensions of the boiler; and it will be seen by reference to the above (refers to various pressures at which the valves were tested) that the pressures of steam, on both the low and high-pressure test made with the ordinary lever valve, rose 11 pounds above the point at which the valve commenced to blow off, while, with the patent valve, it only rose 1 1-2 pounds on the low-pressure, and one pound on the high-pressure trial.

"'The efficiency of the nickel-seated valve was especially noticeable on the final trial, when the valve opened and closed ten times in ten minutes, and maintained the steam over active fires between sixty-nine and seventy-one pounds.

"'The Board, therefore, have to state, in answer to the first interrogatory of their instructions, that the nickel-seated safety-valve is in every way more efficient in its operation to free the boiler from accumulating pressure.

"'In answer to the second interrogatory, regarding the relative promptness, the patent

nickel-seated safety-valve is in every way superior in opening and closing.

"'Regarding the third point of their relative tendency to become inoperative from setting fast, etc., the Board are of the opinion that the use of the patent nickel-seat possesses the very important advantage of lessening the liability of the valve to set fast in its seat.

"'In conclusion, the Board are of the opinion that the addition of this valve to the boilers of the United States Naval vessels will add to their safety and efficiency, and it is recommended for use, and as especially necessary on the high pressure boilers of the compound engines recently built by the Navy Department.

"'Very respectfully, your obedient servants,

"'H. H. STUART, *Chief Engineer*,

"'President of Board,

"'ALEXANDER HENDERSON, *Chief Engineer*.

"'DAVID B. MACOMB, *Chief Engineer*.'"

CHAPTER VIII.

CORROSION OF MARINE BOILERS.

Ques. What are the causes of the corrosion of marine boilers?

Ans. They are corroded on the outside by water dripping upon them from the deck; by

leaks about the seams, rivet and bolt-heads; by leaky hand-hole plates; by vapor arising from the ash-pans, which are generally kept full of water when the boilers are of the water-leg type, and by the action of the bilge water. Knowing the cause of external corrosion, the remedy is easily applied.

Ques. What is the cause of the internal corrosion of marine boilers?

Ans. This subject has attracted the attention of engineers, ship-owners, and chemists from the time of the introduction of the surface-condenser up to the present day Much diversity of opinion has always existed as to the exact nature of the action which, accompanying surface-condensation, destroys the boiler-plates so rapidly and so curiously. Most of the various explanations which have been given attribute the process of deterioration to galvanic action arising from passing the repeatedly *distilled* water over large surfaces of copper or brass tubes, but the tinning of condenser-tubes and the substitution of iron boiler-tubes and pipes in place of brass or copper has not arrested it. It has been attributed to the corrosive action of certain acids arising from the decomposition of the lubricants, but such action is too limited to do the mischief, and even where little if any lubricant has been used in the cylinders the results have been the same. Many panaceas

have been proposed from time to time to cure the malady, such as the injection of solutions of soap and soda; of muriatic acid, etc. Much was at one time expected as the result of the simple plan of placing plates of zinc at different points in each boiler. The corrosion, it was stated, was confined to the zinc, while the iron of the boilers escaped. The zinc cure was reported in some cases to have been an advantage, while in other cases it appears to have been entirely inoperative. The use of strainers or filters by which grease was taken out of feed-water was also held to be a remedy, but this scheme like many others, died a natural death. In fact, many cases are known where boilers working with engines into the cylinders of which no lubricant whatever was admitted decayed just as rapidly as though oil or tallow had been admitted, and others in which all the remedies referred to were applied have also met the same fate. The profession now seems inclined to account for the corrosion by the action of the redistilled sea-water itself, and this view seems to be substantially confirmed by the Perkins system, where it is seen that a boiler thirteen years in constant daily working, using pure rain water over and over again, without change, for all that time, is found to be in a good state of preservation. This case, with many other well-authenticated instances which

have come under my notice, seems to establish the fact that the evil must be attributed to the use over and over again of *distilled sea-water*, and that no remedy except that of *changing the water in the boilers at frequent intervals* has been found effective. It has been believed by marine engineers that the formation of scale on the surface of the iron protects it from corrosion, but more recent evidence has been produced to the effect that the protection is not due to the scale, but to the condition of the water. The circumstance that scale is found on the iron is simply evidence that the water has been kept in such a condition that it would not cause corrosion, and that is all the scale has to do with the matter. The best thing to do when you have a surface-condenser is to change the water in the boiler frequently. A boiler which is blown out and filled up with fresh water every week or ten days will not suffer much from internal corrosion.

CHAPTER IX.

WATER-TUBE MARINE BOILERS.

Ques. Give me all the information you can in regard to high-pressure marine boilers.

Ans. Ever since the successful introduction of the compound engine on the Atlantic Ocean, the

desire has been to extend the expansion of steam beyond the limits at which it is now worked; and in order to meet this demand, the attention of engineers has been directed toward producing a safe and reliable steam boiler, capable of carrying steam of 100 pounds per square inch and upward. Many plans have been projected, and quite a number of them tested at sea, some of which have been on a scale of great magnitude, involving large expenditures of money. Every one of these new types of boilers practically has, up to this time, proved a total failure. In England considerable professional as well as public interest has been drawn to these failures and many discussions have taken place, and numerous papers have appeared on the subject. Perhaps the most able of the papers referred to, and one which gives a clear and full account of the noted failures at sea, was produced last April, by J. F. Flannery. This paper so completely covers the ground that I reproduce it here, as follows:

* "The almost universal adoption of high-pressure steam at sea has brought with it much inconvenience, notwithstanding its great economy of fuel. The anxiety attending upon the construction and the working of the ma-

* Paper read before the Institution of Naval Architects.

rine boiler is much greater now than formerly, its first cost is largely increased, the expense of repair is much more, and the duration of its life is much less. I think I will have the concurrence of the members in saying that one of the gravest, if not the very gravest and most important, of the questions now arising in connection with the machinery of steamships is the improvement of the marine boiler. And not only does the present practice leave much to be desired, but the feeling in favor of still higher pressures is checked chiefly by the difficulty of designing a boiler which will sustain them safely and efficiently. It is an axiom laid down by theory, and confirmed by practice, that the higher the boiler-pressure and the greater the ratio of expansion, the greater is the economy of fuel. Theoretically this axiom is sustained by the fact that to generate steam of the pressure of 30 pounds per square inch, about 1,190° of heat are required, while to generate steam of 120 pounds per square inch, about 1,218° of heat are required; that is to say, to produce steam of four times the boiler-pressure, less than 1 24-1000 times the heat is required. Again, a boiler-pressure of 240 pounds per square inch requires about 1,235° of heat, or 1 4-100 times the heat of steam at 30 pounds, and contains eight times the initial force. Practically, these differ-

ences are so small, that the same consumption of coal may be taken to evaporate the same quantity of water, whatever the pressure. Theoretically, therefore, we have only to increase our boiler-pressure to reduce our consumption of fuel, were it not that two well-ascertained considerations intervene. First, we have not hitherto been practically able to construct a boiler which, under usual conditions of steamship requirements, will stand a pressure greater than is now in use; and, second, the heat of very highly pressed steam burns up the lubricant in the engine cylinder, quickly destroying the working parts. With the second consideration, however, we have not now to deal; and if we could overcome the difficulty of making a boiler to bear even 120 pounds with safety much improvement would be effected.

"To start from the beginning, let us remember that the thickness of the shell of a cylindrical vessel containing high-pressed steam must, in order to maintain the necessary strength, be increased directly in proportion to increase of pressure and diameter, and that the thickness of the shell may, consistently with the strength necessary for any given pressure, be reduced, if its diameter be also reduced. A very usual size for modern high-pressure cylindrical boilers is, say, 12 feet in diameter, and the thickness of the shell of a boiler this diame-

ter, double-riveted, to bear a pressure of 120 pounds per square inch, would be fully 1 1-2 inches. I am not aware of any examples of boiler-construction where the thickness of the shell-plates has exceeded 1 1-4 inches or 1 3-8 inches, and it is almost doubtful if, considering the practical difficulties of manufacture, a perfectly good job is made with shell-plates of this thickness; at all events, it is generally accepted that to make sound workmanship with a thickness greater than this, is practically impossible. On the other hand, a cylindrical vessel or tube, say 12 inches in diameter, may, for this same pressure of 120 pounds per square inch, be made, if welded, only 3-16 inch thick, and still possess the same proportionate strength, or, for a pressure of 150 pounds per square inch, it would be made practically about 1-4 inch thick, and this would give a factor of safety nearly three-fourths times greater than that possessed by the cylindrical boiler-shell 12 feet in diameter, 1 1-2 inches thick, and pressure of 120 pounds. It is practically certain, therefore, that the limit of pressure with the present type of boiler has been reached; and when we consider how much economy of fuel has been effected by increasing the pressure to its present height, and how much more economy may be effected by still further increasing the pressure, it is seen that the adapta-

tion of an efficient high-pressure marine boiler would meet a great and increasing want.

"Many look for the solution of this problem to the type known as the water-tube or tubulous boiler; that is, the system by which the cylindrical portions of the boiler subject to internal pressure are reduced in diameter and increased in number, the result being that for a given weight of material a much higher pressure of steam is carried, and, indeed, by the reduction of the necessary thickness of the shells a higher pressure of steam is carried, and more economy of coal insured than is possible with any other type of boiler. The other advantages claimed for boilers of this type are that the thinness of the metal interposed between the fire and the water enables the heat to be conveyed more efficiently and with less waste, and also enables the steam to be raised more rapidly; that the danger of explosion is limited; that a damaged tube can be easily replaced; that greater strength proportionate to the pressure being possible in first manufacture, the wear of the metal in the boilers need not, at a later date, enforce reduced pressure, and therefore reduced speed of ship, as is the case with existing types of boilers. It is pointed out also that where boilers of the ordinary type require renewal the decks must be broken away, whereas the separate portions of the tu-

bulous boiler may be passed down the hatchway; and, further, that, a war-ship on a foreign station must either return home or to the nearest dock-yard in the event of any serious wear upon ordinary boilers, but so many spare tubes of the water-tube system might be carried as to greatly extend the period of service upon a foreign station.

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"The direction of the flame in the ordinary boiler is always along the faces of the heating-surfaces, whereas in the water-tube boiler it is in a direction at right angles to them; the heating efficiency of flame striking the plate directly, as in this latter case, must be much greater than when sliding along the surface, and we see, therefore, that this system not only enables thinner plates conveying the heat more perfectly to the water to be used, but also directly increases the action of the flame itself. Again, the escape of the steam-bubbles from the metal surface upon which they are generated is more rapid and direct when that surface is disposed horizontally. The condition most essential to safety is beyond doubt good circulation. The heat to which a tube immediately over a fire is exposed amounts to upward of 2,000° ; the specific heat of water, or its power to absorb heat, is twice that of steam, and, in addition, the evaporating water ab-

sorbs the latent heat of steam, making its receptive power many times that of steam; there is, therefore, no difficulty in arriving at the conclusion that a tube of, say, 3-8 inch thickness, which is not relieved by freely-circulated water, will become hot and dangerous in a very few seconds, and it may be shown that the absence of provision for this good circulation has been the primary cause of the difficulties the water-tube boiler has yet encountered. It is noticed, on reference to the diagrams, how large a body of water is contained by the ordinary boiler, as compared with the volume of water held by the water-tube boiler in proportion to their heating and grate surfaces. The effect of this is that the ordinary boiler has a large reserve of water at nearly boiling-point, and is not therefore exposed to such sudden fluctuations of pressure, with their attendant evils, as the water-tube boiler. If the strength of the fires be suddenly increased in a water-tube boiler, a spasmodic rise of pressure, leading to accumulation of steam in the water-chambers, priming, loss of water, and overheated tubes, takes place, and this defect is quite absent from the ordinary boilers; and not only so, but the large reserve of water in the ordinary boiler, the whole of which above the fire-bar level must be heated to nearly boiling-point, is the cause of a much

more gradual, and, therefore, more easily-effected circulation of the water; indeed, the small volume of water is still further reduced in the isolated subdivision of the parts, each tube having to supply, circulate, and evaporate in a very independent manner, and with little reference to the volume of water contained by its neighbors. Clearly the smallness of the contents of a tubulous boiler is in some respects a serious drawback, although it is in other respects an advantage. The difficulty of obtaining a good circulation is from the nature of the case greater in the tubulous boiler, and the increased friction of the water due to high pressure adds to this difficulty, while at the same time it increases the necessity, and it is a matter for the earnest consideration of inventors whether artificial circulation, produced by subdivided feed-inlets, or otherwise, may not after all be resorted to. This idea has been expressed to me by one of our most eminent marine engineers, and it does seem that the certainty of good circulation thus obtained would compensate for the complication of working parts. One element of danger absolutely possessed by the water-tube boiler, and not shared by the ordinary boiler, lies in the fact that the metal exposed to the direct action of the fire is at the same time subjected to the tensile strain of inter-

nal pressure. In the ordinary boiler the parts subjected to tensile strain are not acted upon by the fire, and those parts acted upon by the fire have the water surrounding them with a compressing strain. Although the crushing strain of wrought-iron is less than its tensile strain the case in point of the fire playing upon iron under tension is more dangerous, because any flaws will be stretched out, the flame will penetrate them, and promote their increase to bursting-point.

"The water-tube boiler has, under several designs differing in their details, been extensively used for the generation of steam in factories, and for other stationary purposes, both in England and America; and, although some important defects exist, and some unfortunate failures have occurred, still it cannot be denied that, as a rule, its results have been fairly satisfactory. Why, then, has it not come into more extensive use at sea? It may be answered generally, that the conditions to be fulfilled on board ship are more stringent, the space alloted is more circumscribed, and the boiler must conform to its limits. A less leisurely and methodical action is necessary than in a machine used for stationary purposes, and defects of little importance on land develop into serious evils at sea. We may best elucidate this question, however, by considering some

of the cases in which the water-tube boiler has been tested for marine purposes, and by analyzing the cause of the failure in these cases. Several practical trials at sea have been made, and the enterprising and truly admirable spirit displayed by two steamship owners especially cannot be too highly commended. The gentlemen alluded to are Mr. S. B. Guion, of Liverpool, the managing owner of the steamship *Montana*, and Mr. W. H. Dixon, of Liverpool, the owner of the steamship *Propontis*. The examples in these vessels being the most recent and by far the most important trials of the water-tube system, I propose to ask your attention to them first.

"The *Montana* is a steamship of more than 4,000 tons, and was built for service on the Guion line between Liverpool and New York. Among other innovations, she was fitted by Messrs. Palmer, of Jarrow-on-Tyne, with boilers intended to work at 100 pounds pressure, and it was anticipated that the economy of fuel would be very great. Figs. 15 and 16 * * * will convey a good idea of the nature of the design. Each boiler was composed of tubes 15 inches in diameter, and 15 feet long, sealed at the ends, but communicating with each other by vertical necks about 6 1-2 inches in diameter. There were five horizontal, or nearly horizontal rows, of these tubes in each

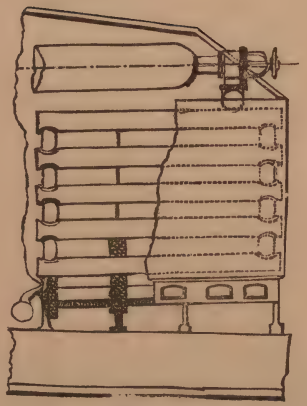

Fig. 16.

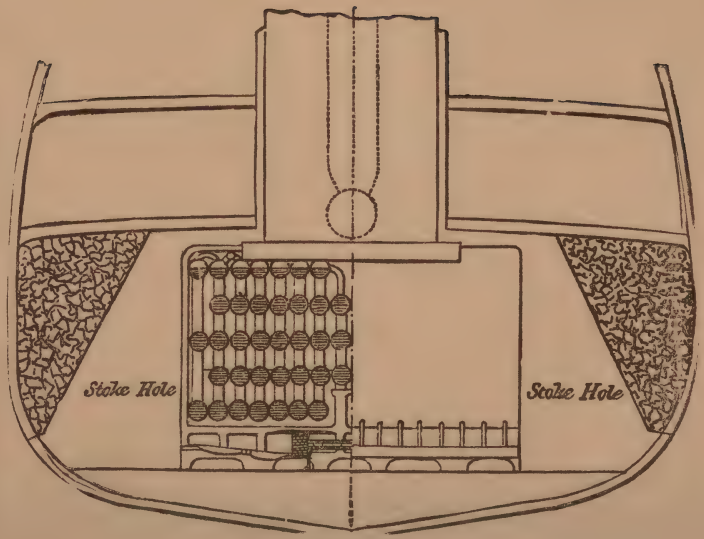

Fig. 15.

BOILERS OF THE S.S. MONTANA.

boiler, and each row contained seven tubes. Noticing the profile, it will be seen that to carry off the steam generated, and to promote the circulation of the water, each horizontal tube was supplied with two necks. As the steam must all rise to the top, the necks between the bottom tube and the one immediately above must take up the steam generated in the bottom tube ; the neck between the second row from the bottom and the one immediately above it must take not only the steam generated in the second, but also that in the first row, and so on, the neck nearest the top having to convey the steam generated in the whole of the tiers of tubes below it. In addition to these tubes, there are in the uptake three steam reservoirs, or superheaters, 3 feet in diameter. In designing the boiler, the two vertical rows of tubes nearest the fire-door were set apart for the purpose of heating the feed-water, and the six other vertical rows of tubes farthest from the fire-door were set apart to generate steam from the feed-water so heated. In accordance with the duty thus assigned to them, the two rows of tubes vertically nearest the fire-door had the feed-pipes connected to them at the top and had small pipes only 7-8 inch in diameter fitted also at the top, to carry away any steam which might happen to be generated. It was, of course,

expected that the current of the feed-water passing through these two feed-heating sections would be so rapid, and that the fire under them would be so much less vivid nearest to the dead-plate that the water could not, while in them, absorb sufficient heat to evaporate. The water was delivered from these feed-heating sections into a large feed-water chamber, which supplied the other sections. The two sections designed as feed-heaters are so-called, though as a matter of fact they were not feed-heaters only, but calculated to generate steam nearly as much as any of the other tubes in the boiler, and the steam had really no outlet, because the 7-8 inch pipe provided for the purpose was so small as to be practically useless. The natural action of the steam generated in these sections was, therefore, to rise to the top tubes, to accumulate there, and to depress the level of the water, driving it out through the bottom pipes from all that vertical section of tubes, and finally exposing to the direct action of the fire a bottom tube filled only with steam, or steam and a small quantity of water. This is exactly what did take place, and on the first trial-passage of the vessel from the Tyne toward the Mersey, five of the tubes burst. These tubes were all situated in corresponding places in the different boilers; that is, the lowest tube in the inner feed-heating section.

After this experience, the connections were altered so as to join this inner feed section to the rest of the steam-generating part of the boiler, leaving the outer vertical row only to act as a feed-heater. For some few hours this arrangement gave promise of better success; but, after a day and a half's working, two more tubes, one of them the fourth from the front in the bottom row, gave way; and the owners, completely discouraged by these failures, taking into consideration also the fact that the boilers were heavier and more bulky than boilers of the same power of the ordinary kind, decided to condemn them, and replace them by ordinary cylindrical boilers. The cause of the failure of the section devoted to feed-water heating appears sufficiently obvious, and as the separation of these sections was a special feature in this example, and is not likely to be repeated in other water-tube boilers, we may dismiss it from further consideration. But the bursting of the other tubes is more serious, and appears to more closely affect the general principle of water-tube boilers. A very able article, from which some of the particulars given above have been drawn, appeared in the *Nautical Magazine* on the subject of the *Montana's* boilers, and it is there suggested that the cause of the explosion of the inner tube on the bottom row was the absence of a suffi-

ciently large steam connection between the top or steam-holding chambers to counteract the inequality of pressure in them.

"It will be noted that the feed-pipes for all the sections are common to one feed-water chamber, and, supposing any inequality of steam-pressure to exist, the water would, of course, be forced from the chamber containing the highest pressure to those containing a lower pressure. The steam-pipes connecting the upper chambers were 2 inches in diameter, and the area of the fire-grate under each section was about 7 3-4 square feet. A very simple calculation shows that these 2-inch pipes were very small, if any large difference in pressure was to be equalized. Another explanation, and one which appears quite reasonable, was advanced by Mr. John Watt; he calculates that the grate-surface, 7.75 feet, acting upon the water in each bottom tube, is equal to the evaporation of 12.83 pounds of water, or 78 cubic feet of steam at 50 pounds pressure per minute. Now, the only orifices through which this quantity of steam may escape are the before-mentioned pair of 6 1-2-inch vertical necks; which have each an area of 33.18 square inches; one of these would probably be a downcast for the water, and the other, at the higher level, being an upcast for the steam, the steam would therefore rush through this neck at the rate of

nearly 340 feet per minute, a speed so great that the assumption that the steam would drag the water upward from the bottom tubes, leaving them exposed to the fire, does not seem exaggerated. Whichever of these explanations be correct, it is evident, in the light of the experience now gained, that the failure of these tubes in the *Montana's* boilers proceeded from easily-preventible causes, because in a future design the feed-water arrangement could be omitted, and the steam connections to equalize the pressure in the different sections could be enlarged, the vertical necks for the escape of the steam could be much increased in area, and it is possible that if these alterations had been effected upon the *Montana*, a result very nearly approaching success would have been obtained. Indeed, it was most unfortunate, in the interests of science, that no further experiments were made with this vessel; she was condemned after a series of trials extending altogether over not more than five or six days.

"The *Propontis* is a steamer of about 2,000 tons, belonging to Mr. W. H. Dixon, of Liverpool. In 1874 she was fitted by Messrs. John Elder & Co. with boilers on the water-tube principle, under Rowan & Horton's patent. * * * They are four in number, having one chimney, and each boiler consists of seven hori-

zontal cylindrical vessels, connected together by vertical tubes 12 inches in diameter, supplemented by numerous pipes 2 1-2 inches in diameter; the space for steam in the upper vessels being increased by four diagonal domes. To further guard against priming, tubes are carried directly from the steam-dome down to to the lowest vessels, so that any water carried up by the steam will be broken from it in the upper chamber and fall down again to the lowest level; the feed is also delivered at the bottom chambers. Baffle-plates are fitted to circulate the flame among the tubes. * * * The lower or water chambers were connected, but no connection was made between the upper or steam chambers; the importance of this omission is obvious, and was discovered in the working of the boilers, as will be seen further on. The working-pressure intended was 150 pounds. While the defects in the boilers of the *Montana* exhibited themselves after a very few hours' work, the boilers of the *Propontis* continued their promise of success for a much longer period, and, indeed, were exhaustively tested at sea for a time extending over several months. The first voyage of the *Propontis* was from Liverpool to the Black Sea and back, and very careful observations of the working of the boilers were made. The consumption of coal, taken during a run of 10 hours, was

1.54 pounds per indicated horse-power per hour ; the pressure of steam being easily maintained at 130 pounds to 140 pounds. It is by no means certain that the full advantage of the *Propontis's* boilers in point of economy is represented by the above figures, because the baffle-plates for the deflection of the flame were not arranged just in the way that experience afterward showed they should be arranged, and consequently much unconsumed gas escaped up the chimney. So far the career of the tubulous boiler in this ship was fairly satisfactory and sufficiently promising; but before long, evils, which had been gradually accumulating, developed themselves in an unpleasantly conspicuous manner. * * * Some of the smaller-sized vertical tubes terminate in S-bends at the points where they join the horizontal vessels. The peculiarity of this bend rendered it impossible to clean the tubes from scale, so that salt water could not be used; indeed, precautions of an unusually perfect character were taken to admit pure distilled water only to the boiler, and the action of this distilled water, unmixed with any salt, was just what might have been expected; a corrosive action was set up in the tubes; some parts of the internal surface were quite untouched, while other parts close to them were perforated by circular blotches of corrosion of 1-2 inch to 1 1-2 inches

diameter. These were continually giving out, allowing the steam and water to escape upon the fires. The defects were temporarily remedied by drawing the fires and binding a ligature round the injured tube over the hole; and these little explosions were of such frequent occurrence that one of the four boilers was almost constantly disconnected.

"In the early part of 1875 the boilers underwent a thorough repair, being supplied with some 300 new tubes, and were tested by water pressure to 275 pounds. After this a small quantity of sea-water was allowed to enter the boilers to make up the waste, and after completing another voyage to and from the Levant, her boilers were opened up and found to be coated with a slight scale. In September of last year she commenced another voyage, but on the third or fourth day the wing-chamber of the forward starboard boiler burst, injuring two men, the pressure at the time being 150 pounds. The rent was nearly 2 feet long, and was in the solid plate near the lower side of the tube, and about its middle length. At Lisbon this was repaired by riveting a patch 3-8 inch thick. Leaving Lisbon, she had been but a very few days out before another explosion took place, the pressure at the time being only 105 pounds. The fracture was in the wing-chamber of the starboard after boiler, and was

again in the solid plate, at the lower side of the chamber; the rent measured 12 inches by 7 inches. The diameters of the tubes which gave way were 21 inches, the plates 3-8 inch thick, and the bursting pressure of this would be 1,200 pounds, provided the plates were cool and uninjured. Putting into Algiers, the boilers underwent an inspection by French engineers, and in accordance with their advice the furnaces were partially bricked up, and the pressure reduced to 60 pounds. It may be here remarked that the opinion of the French engineers that a reduction of pressure meant, in the case of these boilers, greater safety, was very questionable. It may be a paradox to say that the lower the pressure the greater the danger, but in the case of water-tube boilers, under certain conditions, that is the fact. Let us remember that a cubic inch of water will make a cubic foot of steam of the same tension as the atmosphere, and that the greater the pressure the less is the bulk of any given quantity, say a pound weight of steam. Now, as the power of a boiler may be measured by the number of pounds weight of steam that it evaporates, the *Propontis* boiler would evaporate no really greater quantity of steam at 60 pounds pressure than it could evaporate at 150 pounds pressure; but whatever steam it did evaporate would at 60 pounds pressure occupy

more than twice the space it would occupy if at 150 pounds pressure. Again, evaporation cannot take place without circulation, and circulation is the mutual changing places of the steam as it is generated and the water about to be evaporated; if, therefore, the steam occupies twice the volume, then there will be twice the space for it to travel through to circulate or change places with the new water; and as one dangerous defect in the *Propontis* was insufficient circulation, it is seen that by lowering the pressure the French consulting engineers may not at all have increased the safety of the boiler. It is a most interesting investigation, but one which I fear can only be conducted practically to learn how far the increased friction, varying directly as the pressure, compensates for the decreased volume of the evaporating steam. The vessel was towed from Algiers to Gibraltar, and then the extra fire-bricks were taken out, a baffle-plate between the chambers and the fires was fitted, and test-cocks were placed on each water-chamber. Under the protection of the baffle-plates, and the careful watching of the water-level made possible by the test-cocks, the vessel steamed home with three boilers.

"Upon final examination it was found that the vertical tubes were bulged and distorted in several places, and all the horizontal tubes

exposed to the direct action of the fire were more or less bulged upon their lower sides, thus affording clear evidence that in most of the water-chambers of the boiler steam was sometimes collected. These bulgings or partial injuries to the boiler evidently arose from defective circulation, and the bursting or more serious injuries were the result of the unequal pressure of steam in different sections. There was no pipe connecting the steam-chambers of the two boilers, and although the steam-chambers were not connected, the water-chambers were, so that any increase of steam-pressure in one boiler simply had the effect of driving the water out of its own chamber into the other boiler. Not only was the unprotected plate exposed to the fire, but the abnormal increase in the water-level of one chamber held out every inducement to priming. This serious structural omission explains the bursting due to overheating, and at the same time the priming which occurred. It is very remarkable that the partial abscence of a similar pipe contributed to the failure of the boilers of the *Montana*. It has been suggested that the burstiug of the tubes in the *Propontis* arose not so much from defective circulation of the water as from corrosion and consequent weakening of the plates; this is the fact as regards the small circular perforations, but the same explanation does

not apply to the longitudinal rents, and is not borne out by an examination into the character of the larger fractures. The longitudinal rents which caused the loss of life occurred in portions of the tubes practically uninjured by corrosion, and it was found that the fracture showed only a slightly reduced thickness of metal, and that at a distance of about 1 inch from the lip of the rent the plates resumed their original thickness. The bursting-pressure of the rent tube was, as already stated, 1,200 pounds per square inch, and the uncorroded appearance of the fractured portions points to the conclusion that defective circulation and overheating caused the explosion. The plates, if hot, would stretch a little before giving way, and the confined space over which the thinness extends seems to show that it should be traced to stretching only.

"The *Birkenhead* is one of the large passenger ferry-steamers running between Liverpool and Birkenhead. She was built in 1872, and fitted by the Patent Steam-Boiler Company, Birmingham, with tubulous boilers, on Root's patent. The boilers * * * were each divided into fifteen sections, each section consisting of eight horizontally-inclined tubes, 11 feet long, by 6 inches in diameter; these tubes were at the ends connected to small cellular vessels. Communication between these vessels in their

respective horizontal tiers was affected by bent pipes bolted to them. * * * The working pressure was 40 pounds, although in designing the boiler the pressure was intended to be 60 pounds. * * * It is only fair to the manufacturers to say that they labored under the difficulty of very confined head-room; these vessels are of limited draught, and as a flush deck is necessary for the passenger-traffic, the vertical space at the disposal of the designer was quite insufficient to give boilers of this type a fair chance of success. The boilers were for the first few months of their existence worked with impure water, and considerable trouble from overheated tubes was the consequence. A fresh-water tank was afterward fitted, and with an improved result, but still it was found that the tubes in the bottom row were continually bulging and giving out from overheating, and the vessel was frequently off duty for repair. The exit of the steam was no doubt retarded by the turnings and counter-turnings it underwent before reaching the surface. The greater vertical distance through which the steam rises from the surface of the water before rushing to the engine, the less is the tendency to carry water away with it, not only because there is more time given for the water to fall back from the ascending stream, but because the pull caused by each stroke of

the engine is less severely felt at the bottom tubes if they are some distance below the steam outlet. * * *

"In this design a very small height was between the stop-valve and the bottom tubes, and the engines being paddle-engines with large cylinders and slow stroke, there is no doubt that the tendency of the water to forsake the bottom tubes was greatly enhanced from this cause, although primarily due to imperfect circulation. The defect would also be increased by the stoppages and the lying-to of the vessel in her work as a ferry-steamer, allowing accumulations of the steam-pressure. Not only so, but the deficient room rendered it impossible to get in so much boiler-power as was afterward thought necessary, and the manufacturers allege that consequent forcing of the fire contributed in no small degree to the failure of the tubes. The sister ships to the *Birkenhead*, working on the same station, and with very similar engines, but boilers of the ordinary type, offered an excellent standard of the average consumption of coal, and the saving in the *Birkenhead* by comparison with one of the boats amounted to 17 per cent., and by comparison with the other to 25 per cent. This result is the more remarkable when it is remembered that the pressure was only 40 pounds, and that the expansion in the engines

of the *Birkenhead* could not be greater than in the sister ships; the comparative economy was therefore entirely due to the more effective arrangement of the parts, the thinness of the metal in the tubes, and the direct action of the flame upon them favoring the evaporation; had the pressure been higher and the expansion greater, the economy would no doubt have been largely increased. Notwithstanding the excellent result in point of economy, the ferry management condemned the boilers after nearly three years' work, on account of the continual breakdowns, and the vessel is now fitted with boilers of the ordinary type made by Messrs. James Taylor & Co. The cause of the comparative failure of these boilers has already been indicated; the twisted passages for the exit of the steam, and the low vertical height, added to heavy firing, caused the bottom tubes to be occasionally full of steam, and being exposed to the full action of the fire, they were quickly destroyed.

"Another vessel fitted with boilers on a Root's patent, and of very similar design, but still more contracted passages for circulation, was the steamship *Malta*, of 2,000 tons, belonging to the Merchants' Trading Company, Liverpool. They were in this case found to give off steam with great rapidity, and steam could be raised in them in about half the time necessary in

boilers of the ordinary type. The working-pressure was 50 pounds. The boilers went on about twelve months, during which time the vessel visited the Mediterranean and the Baltic. Very little priming took place, but the same defect as in the other cases developed itself, the circulation of the water was insufficient, some of the bottom tubes nearest the fire bulged and gave out, and the boilers were finally taken out, to convert the vessel into a sailing-ship. The engines were very old before the Root boiler was fitted, and their worn-out condition contributed to the owners' decision to alter the vessel. I am informed that many of these Root boilers, of the same manufacture, are working successfully on land, and where large space may be given and leisurely delivery of the steam is possible, they have been found highly successful.

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"Boilers were fitted to the steamships *Amalia* and *Palm*, under Ramsden's patent. These boilers worked very satisfactorily for about four years, but at the end of that time it was found that the construction of the boilers not fully providing means for the removal of the incrustation, the plates had seriously deteriorated, and the boilers were consequently removed.

"Trials were made of the Howard patent

safety boiler in the steamships *Fairy Dell*, *Meredith*, and *Marc Antony*. These boilers were all constructed about the same date, 1870. Their working on board ship in all these cases was quite unsatisfactory; the lower tubes burst, others leaked, and very great priming took place. These results were traced to the same general causes that led to the difficulties experienced with the *Birkenhead* and *Malta*, and it is unnecessary to discuss them in detail.

"After discussing so many failures of the water-tube system, I cannot close this paper without describing the most recent working example of the tubulous boiler for marine purposes. One of the earliest advocates of the tubulous boiler is Mr. John Watt, of Birkenhead, and his system is shown on the diagrams (Figs. 17 and 18). The diagrams represent the boiler of the steam-flat *Gertrude*. 'The boiler consists of a series of inclined tubes connected at their ends to rectangular water-chambers. To the top of the chamber is connected a steam-receiver, from whence the steam is taken to the engines. The rectangular chambers are stayed like the ordinary locomotive fire-box, by means of stays through the door and tube-plates, one end of each stay being left sufficiently long to enable the tube-doors to be secured. The tubes are in diagonal rows, and the course of the flame is in zigzag direction among them.' A very brief con-

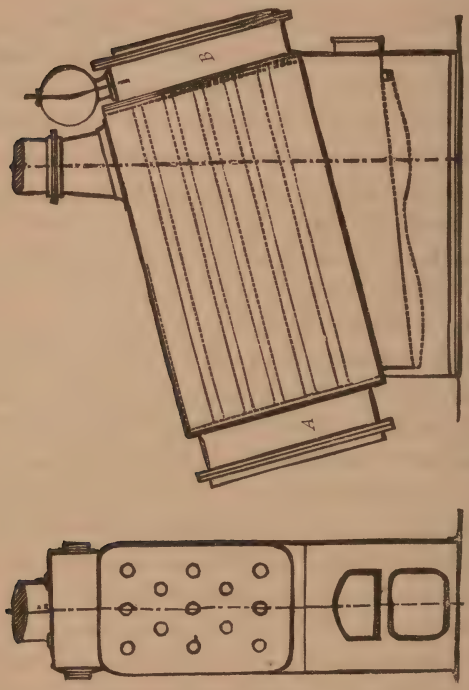


Fig. 17. BOILER OF THE "GERTRUDE."

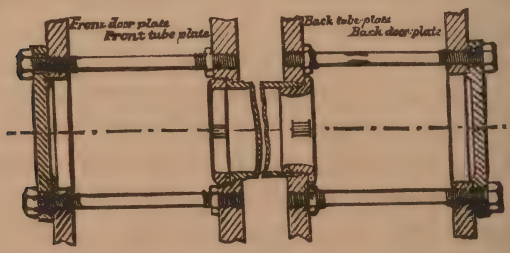


Fig. 18. DETAIL OF GERTRUDE'S BOILER.

sideration of the natural action of the steam and water in this boiler will show that it possesses features superior to some of the boilers already described. As the steam is generated in the tubes, the angle at which they are inclined will facilitate its ascent to the upper rectangular water-space, B, and once there, its ascent to the steam-receivers is easy and certain, its upper passage being unobstructed; at the same time, the water to take the place of the steam generated contained in the lower rectangular chamber, A, will, by a natural action, ascend from it, and so a good circulation is secured. The necessary feature in a boiler of this arrangement is a separate outlet for the steam, and a separate inlet for the circulating water; any contention between the ascending steam and the descending water must be fatal.

"The shorter and wider the tubes are made the greater will be their safety, because the amount of evaporation will vary as the heating surface of the tube. Now, the surface of the tube increases directly as the diameter, but the volume contained increases as the square of the diameter, and this fact goes far to explain the danger of long, narrow tubes, the length still further increasing the difficulty of the exit of the steam. In the case of the *Propontis*, some of the small vertical pipes were so far attenuated as to be 8 feet long and 2 1-2 inches in

diameter. I am informed that the *Gertrude's* boiler has worked for some months, and with so perfect a circulation that no deposit or scale has been formed, although partially salt water is used, and the engine is not fitted with a surface-condenser. Another design, strongly advocated by the inventor, is that of Mr. Wigzell. * * * This is a compromise between the tubulous boiler and the boiler of ordinary type; the flame will surround the inclined cylinders, and the other cylinders being perforated with tubes, it will pass through these on its way to the chimney, its exit through them being made compulsory by blocking up the outer spaces between the cylinders by diaphragm plates. No boilers of this design have yet been tried at sea, though the inventor assures me that most satisfactory results are obtained by its use for land purposes.

"We set out with the statement that, so far as present lights enable us to judge, greater economy in the use of coal at sea can only be obtained by increased boiler-pressure; that cylindrical vessels of small diameter are the only practical generators of high-pressure steam; that up to the present time no water-tube boiler on a large scale has given perfectly satisfactory results at sea; and that the practical trials already made are in themselves sufficient to teach useful lessons, and perhaps to indicate

to some extent the practice of the future. If there is some specific features in the design of the boilers of the above-mentioned ships which is common to them all, and has contributed to their failure, then a valuable lesson will have been drawn from them. Insufficient circulalation of the water has been more or less a characteristic of the above cases, and to get at the root of the matter it is necessary to discover why the circulation has been insufficient. In the ordinary boiler the reservoir for steam is vertically above the surface upon which it is generated, and no obstruction to its ascent is offered except the friction through the superincumbent water. Looking at the diagrams, it will be seen that the steam generated at certain portions of the boiler surface, in all the examples of water-tube boilers, must travel a greater or less distance horizontally, or nearly horizontally, before it can make its movement in a vertical direction, and in some of the cases the steam encounters repeated obstructions to the horizontal deviations from its continued ascent through the water. No difficulty of this kind is to be found in the ordinary marine boiler; the steam as it is generated ascends by a free and natural action through an unobstructed body of water, and it is only when steam can move in a vertical or nearly vertical direction that it has any tendency to

circulation at all. To design a boiler in such a manner that the steam shall move in a horizontal direction for ever so short a distance, is to lay down a wrong principle, because the horizontal movement can only be borrowed from the force developed in those particles of steam which are ascending, and which jostle, so to speak, their neighbors along the horizontal portion of their journey. Now, the greatest obstruction to circulation at high-pressure, apart from the arrangement of the tubes, is the great friction. An arrangement which at a lower pressure would give fairly good results, will quite refuse to produce proper circulation when the friction is seriously increased by high-pressure, and it is evident that a high-pressure water-tube boiler must, if it does not depend on artificial circulation, have no portion of its interior so arranged that a horizontal flow of the steam through the water is necessary. The features which the successful marine high-pressure boiler must possess are, a clear vertical lead for the steam as it is generated, separate downcasts for the water and upcasts for the steam, and accessibility for the removal of incrustation. Whether the designs introduced, but not yet fully tested, may be found to give better results than some of those we have named is a problem yet to be solved.

"I have to express my thanks to the various

manufacturers and other gentlemen who have assisted in the preparation of this paper; and having briefly reviewed some of the principal experiments already made at sea, with the tubulous boiler, it remains to say that the Admiralty is now engaged in a trial of the high-pressure boiler on Perkins' system, and no doubt the results will in due time become generally known.

"So far as we may now judge, it does appear that the water-tube boiler, designed scientifically and in accordance with the experience the past failures have taught, holds out prospect of much more satisfactory and profitable work than has yet been obtained by its use at sea.

"The most extensive and costly of the boiler experiments represented in the foregoing paper was the one made by the Guion line of steamers. In addition to the boilers fitted on board the steamship *Montana*, and tested at sea, the *Dakota*, a sister ship, was also fitted with the same kind of boilers, and although the boilers in this ship were not quite completed when those in the *Montana* were condemned, they too were at the same time removed to the scrap-heap. The cost of the boilers for each of these ships was $175,000, and it is believed that the total cost to the company for this experiment has been not less than $486,000. It has been estimated that during the last seven

years the total cost in Great Britain resulting from the failures of boilers designed to be worked at sea with pressures of upward of 100 pounds per square inch, has nearly reached the enormous sum of $1,000,000."

CHAPTER X.

REPAIRS AT SEA.

BOILERS.

Ques. What kind of repairs can be made to boilers at sea?

Ans. Owing to imperfections in the iron, small cracks often appear in the crown-sheet, flues, and back connections. If in the crown-sheet, and not more than *two* inches in length, drill a hole, cutting the crack out, cut a taper thread, and insert a wrought-iron gas plug (a number of which of different sizes should be carried for that purpose) smeared with white lead.

If in a flue, drill a number of small holes, and put in small rivets, hammering the heads out so as to cover the crack.

If the crack is more than two inches long, or if it be a large hole which cannot be plugged, then you must put on a hard patch, and if the patch cannot be riveted on, then put it on with tap-bolts screwed into the sheet; care must be

taken to admit water to the patch, else the fire will soon destroy it.

Hard patches should be used on all parts reached by the fire, and soft patches on the other portions.

Ques. What is the difference between a hard patch and a soft patch?

Ans. A hard patch is riveted on or put on with tap-bolts; a soft patch with bolts and nuts.

Ques. What is the proper way to put on a soft patch?

Ans. You first make a pattern of the needed patch out of sheet-lead, then take a piece of boiler-plate, and forge a patch as near like the lead pattern as possible. Then drill as many 5-8 holes as are necessary, about 3 inches apart in the sheet, and corresponding ones in the patch. Next, mix some boiler-maker's cement, which is made of equal parts of white and red lead mixed with enough iron borings to make it a stiff putty; cover the inside of this patch with this putty, and it is ready to go on. Next, wrap some 5-8 bolts with lampwick smeared with white lead, pass the bolts through from the *inside*, and set the nuts up tight, placing a washer between all the nuts and patch.

Ques. Suppose the patch is so situated that the bolts cannot be put through with the hand?

Ans. Then they must be "fished" through.

Take a long piece of wire, pass it through the bolt-hole and out through the hand-hole, then tie the bolt to the wire with a piece of strong string, giving about an inch slack, haul out the wire and the bolt will come out nicely in its place. This is called fishing a bolt, from its resemblance to hauling in a fish.

LEAKY TUBES.

Ques. What is the proper way to plug up a leaky tube?

Ans. Suppose the tube is 3 inches in diameter, and 7 feet long. You take two white-pine plugs 3 inches in diameter, tapering off to 2 7-8 inches, and about 4 inches long. Next, bore a 3-4 inch hole through the centre of the plug. Take a 5-8 inch bar, 7 feet 4 inches long, with a thread cut two inches in length on each end. Run the bar through the tube, put in the pine plugs, and drive them in flush with the tube. Place a saucer-shaped washer filled with red lead, putty, or boiler-maker's cement, on each plug, and screw up tight with nuts.

The following cut will show at a glance how this is done:

Fig. 19.

Ques. Are not iron plugs sometimes used instead of wooden ones?

Ans. They are; but they are inferior to dry white-pine plugs, for the reason that when the pine plugs become saturated with the hot water, which they do in a short time after insertion, they swell, and make a perfectly tight joint, whereas iron does not.

Ques. Should not every steamer carry a number of bars, washers, and turned pine plugs for this particular purpose?

Ans. Old boilers generally give out in the the tubes first, and, therefore, a half-dozen bars, with nuts, washers, and plugs complete, should be kept on hand ready for use. The plugs should be turned and bored by machinery, as it is a difficult matter to whittle them true with a jack-knife, and, unless they are true, the tube will be apt to leak after they are put in.

CHAPTER XI.

ABUSE OF STEAM BOILERS.

Ques. To what cause can you ascribe the general neglect of steam boilers?

Ans. It would be difficult to assign any reasonable cause for this neglect, except that it may arise from the fact that nearly the whole

attention of the mechanical engineer has been concentrated on the improvement and perfection of the steam *engine*, and the marine engineer, following the example of the constructors, generally neglects his boiler, and devotes all his time and care to his engine.

Ques. Will you name in what particular way boilers are generally neglected and abused?

Ans. One of the most common, and at the same time greatest, abuses of the boiler, is the reckless practice of blowing out the water as soon as the fires are hauled, and the boiler still hot. Under such circumstances the contraction of the crown-sheet, tube-sheets, and tubes is so unequal and rapid, that it results in the end in the ruin of the boiler. Boilers well made, of good material and design, have been ruined by blowing them out under a heavy pressure of steam, and then immediately filling them with cold water. After the fire has been hauled, the connection doors and furnace door should be opened, and the boiler be permitted to cool off before the water is blown out, which should be done under a pressure of not more than 10 pounds—the less the better—otherwise leaky seams and tubes, or fractured stays or braces will be the result. Some engineers seem to think that mud and other deposit can be *blown out* by a heavy pressure of steam, but this is an error, as all the older members of the

profession well know. Another abuse is the pumping of cold water (sometimes ice-cold water in winter time) into the boiler with the donkey pump. Now, unless you can pump hot water from the hot-well with the donkey pump, it should be used sparingly, and that only when the boiler cannot be pumped up by any other means. As a general thing boilers leak most at that point where the cold water from the donkey pump impinges upon the metal.

Another abuse is that boilers are not cleaned out often enough, but the scale-deposits are allowed to accumulate on the crown-sheet, tubes and flues, until it becomes so hard and thick that the water cannot protect the iron, and it is burnt and destroyed.

In all cases when boilers are laid up or out of use they should be opened, cleaned out, and examined to see if the stays or braces are broken, loose, or much worn. At the same time the hammer-test should be applied to all accessible parts. All oxidation should be removed, and such places painted with good red lead or "poco" paint.

CHAPTER XII.

TESTING BOILERS.

Ques. In what manner are marine boilers tested as regards their strength, etc.?

Ans. There are two methods in general use, known as the "hydraulic-test" and "hammer-test." The former test consists in filling the boiler with water and then with a hand force-pump raising the pressure up to that which it is supposed the boiler will stand, and then allowing 2-3 of the water-pressure for the steam-pressure. For instance, if a boiler stands a pressure of 90 pounds per square inch water-pressure, 60 pounds would be the steam-pressure. The 2-3 rule is that in use by the U. S. Local Inspectors. The "hammer-test" is applied to all accessible parts of the boiler, such as the shell, crown-sheet, flues, back and front connections, tube-sheets, and braces, by tapping with a light hammer. The experienced engineer can easily tell from the sound produced whether the part struck is sound or not.

Ques. Which test do you consider the better one?

Ans. Some engineers prefer one, some the other, but in my opinion whenever a marine boiler is tested *both* the hydraulic and hammer-test should be applied. But whether one or both, the testing of boilers requires the greatest care and skill, and should never be applied to any boiler unless all the conditions are understood, such as general condition, age, etc., and never except by persons who fully un-

derstand the object and effect of the test. The steam-gauge used during the test should be a standard one, and one *known to be correct* by the person testing the boiler, beyond all doubt. It stands to reason that if the gauge be not correct, the test is useless, and besides you run the risk of injuring the boiler by an excess of pressure.

CHAPTER XIII.

EXPLOSION OF STEAM BOILERS.

Ques. What causes steam boilers to explode?

Ans. The one great cause of boiler explosion is the inability of the boiler to withstand the pressure to which it is subjected at the time; and this may be brought about by any one of the following causes, viz:

1st. Bad design, in which the boiler may not be properly strengthened by stays and braces; deficient water-space preventing the proper circulation of the water.

2d. Bad workmanship, caused by the punching and riveting being done by ignorant and unskilled men.

3d. Bad material, caused by blisters, lam-

ination, and the adhesion of sand or cinders in the rolling of the plate.

4th. By excessive pressure, caused by the gross carelessness or recklessness of the engineer, or by defective steam-gauges, or inoperative safety-valves, they being over-weighted, jammed, or otherwise out of order.

5th. Overheating of the plates, caused by shortness of water, which in turn is caused by the carelessness or ignorance of the engineer, in allowing the water to get low, and then putting on the pump, after the plates have become overheated.

6th. By accumulation of scale, mud, or other deposit, which prevents the water gaining access to the iron. This causes the seams to leak, the crown-sheet to bulge or come down; and when this happens the boiler is in a dangerous condition, and liable to explode.

Ques. Then there is no mystery about steam boiler explosions?

Ans. Certainly not. All steam boiler explosions are caused by one or more of the above causes. Were all boilers of good design, material, and workmanship, and in charge of none but sober, intelligent, and experienced engineers, such a thing as a boiler explosion would be almost unknown.

CHAPTER XIV.

COMBUSTION, ETC.

Ques. What is meant by combustion?

Ans. When coal, wood, or any other combustible matter is brought to a certain high temperature, it acquires a strong affinity for oxygen, —which is the supporter of combustion, and when the oxygen and combustible combine, we say they burn, and in combining or burning heat is produced.

AIR.

Ques. Of what does common air consist?

Ans. Air consists of oxygen and nitrogen (two gases) mixed together in the proportion of one pound of oxygen to 3.29 pounds of nitrogen. In practice 18 pounds of air, or about 240 cubic feet, are required for the combustion of one pound of coal, owing to the imperfect combustion in the furnaces of steam boilers.

COAL, ETC.

Ques. What is the difference between anthracite, or hard coal, and bituminous, or soft coal?

Ans. Anthracite coal consists almost entirely of carbon—containing about 90 per cent. of carbon, and only about 10 per cent. of volatile matter and ashes; whereas bituminous coal

consists of carbon about 70 per cent., and volatile matter and ashes about 30 per cent.

Charcoal is almost pure carbon, so also is that precious gem, the diamond.

CHAPTER XV.

MARINE ENGINES.

SIDEWHEEL.

Ques. How and of what material are the different parts of a walking-beam engine constructed?

Ans. The *beam* itself is composed of a cast-iron *skeleton frame*, around which a wrought-iron strap of great strength is fixed.

This strap is forged solid, and in the forward end is the journal to which are attached the links connecting it with the cross-head, and in the other end is the journal to which is attached the connecting-rod. The skeleton frame is a single casting in the form of a cross, and contains the journal of the air-pump links.

The condensor is cylindrical in form, flanged at both ends, and is of the same diameter as the cylinder. It is made of cast-iron.

The steam-chest contains the valves and seats, and steam passages. They are also made of cast-iron.

AMERICAN BEAM ENGINE.

(SIDE-WHEEL STEAMERS.)

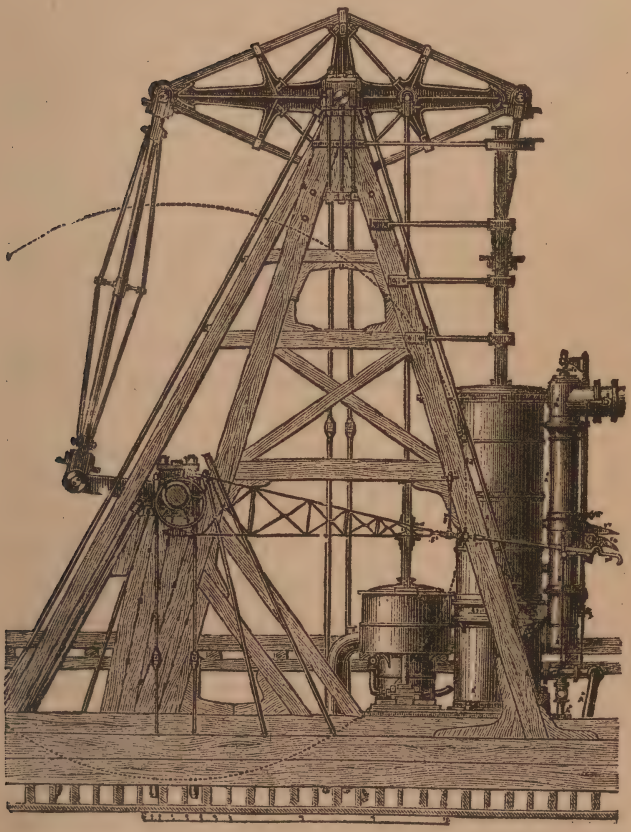


Fig. 20.

The steam-toes on the rock-shaft are considerably longer than the exhaust-toes, and they are so arranged that there is an interval of time between the closing of one valve and the opening of the other. During this interval of time both valves are in their seats, and the steam cut off. This arrangement is what is known as the Stephens cut-off. The manner of setting it, altering the point of cutting off, etc., will be found described at length in the chapter on "Cut-offs."

The binders or guards should never be screwed up so tight as to cause the lifting-rods to hang up, nor should the nuts on the lifters be so tight as to prevent the valve stems having a little side play, otherwise they may not sit fairly in their seats.

The valve-gear consists of four lifting-rods with their lifters and toes, and they are made to lift up and down through binders or guides attached to the steam-chests and side-pipes. The lifters connect the valve stems to the lifting-rods. The upper or lifted toes are attached to the lifting-rods, and stand directly over the lower or lifting-toes on the rock-shaft which give them their up and down motion.

The rocking motion of the rock-shaft causes the lifting-toes to raise and lower the lifting-rods and with them the valves in their seats. The exhaust-valve-toes are of a length just suf-

ficient to give the valve the proper lift, and are so adjusted that the moment one rod is fairly down the other begins to rise.

The side-pipes which connect the steam-chests are made of cast-iron, and are generally turned and polished, though of late it is the practice to cover them with "lagging." At the upper end of the side-pipes, where they are affixed to the steam-chests, is an expansion joint to prevent injury to pipes or chest by the expansion or contraction of the metal.

The valves are the kind known as double poppet-valves. These valves are balanced, or nearly so, in consequence of the downward pressure on one valve being balanced by the upward pressure on the other. The upper valve of each pair of steam-valves, and the lower valve of each pair of exhaust-valves, are somewhat larger than the other of each set, and this unbalanced pressure keeps the valves in their seats.

The trip shaft is a small shaft working in bearings cast on the lower steam-chest. It has small toes attached to it, and it raises and lowers the lifting-rods and valves by small toes keyed to the lifting-rods. The trip-shaft is used when working the engine by hand with the starting-bar. After the engine is "hooked on," the starting-bar is taken out of the trip-shaft. When the Stephens cut-off is used there are four lifting-rods, while with Sickles' there

are generally only two, though four are sometimes used, which is the better plan. Winter's also has four lifting-rods. Stephens' cut-off has two eccentrics, one for the steam-valves, and one for the exhaust. Sickles' has only one for both steam and exhaust valves, though it would be better to have two, and make the exhaust-valves independent of the steam-valves. Winter's has only one eccentric, which *revolves* the rock-shaft; Winter's arrangement uses cams instead of toes to raise and lower the valves.

The air-pump is made of cast-iron, but lined with brass; the air-pump piston is made of brass, and the rod is either of brass, or wrought-iron covered with brass. The air-pump-valves as well as the foot-valves are made of india-rubber. The feed-pumps are made wholly of brass, or of cast-iron lined with brass; the plungers are also made of brass, or iron covered with brass. The valves and seats are also made of brass.

The A frame, or gallows-frame, as it is generally called, is sometimes made of plate-iron riveted together, but the general practice is to make it of wood firmly braced together.

Fig. 21 shows a beam engine with cylinder, condenser, air-pump, feed-pump, etc., but omitting gallows-frame, crank, shaft, etc., for want of space, and because it is not necessary to give them, as they are of minor importance. Fig. 22 shows a front view of steam-chests, side-pipes, valves, etc.

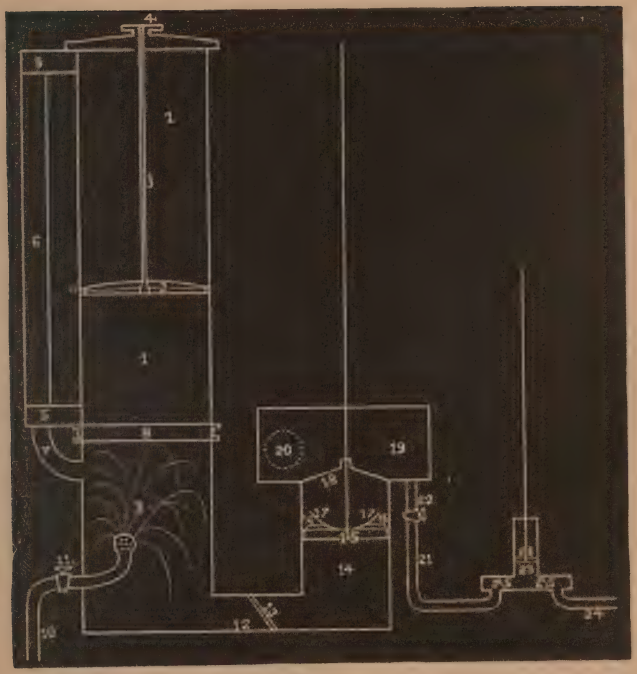


Fig. 21.

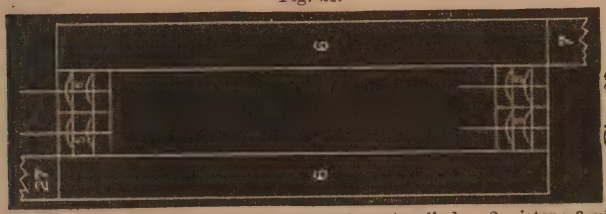


Fig. 22.

The following figures explain the sketches—1. cylinder; 2, piston; 3. piston-rod; 4. stuffing-box; 5, valves; 6, side-pipes; 7, pipes leading to condenser; 8. air-space between cylinder and condenser; 9, condenser; 10. injection-pipe; 11, injection-cock; 12, channel-way; 13, foot-valve; 14. air-pump; 15, air-pump piston; 16. air-pump piston valves; 17, guard; 18. floating tops; 19. hot-well; 20. rut-board delivery; 21, feed-pipe; 22. feed-cock; 23. feed-pump; 24. feed-pipe leading to boiler; 25, feed-pump valves; 26, feed-pump piston; 27, steam-pipe from boiler.

CHAPTER XVI.

MARINE ENGINES (*Continued*).

SCREW ENGINES.

Ques. How, and of what material, are steam cylinders constructed?

Ans. They are made of hard cast-iron, and the harder it is the better the cylinder will withstand the wear and tear of the piston and valves. The valve-seat containing the steam and exhaust ports are cast with it. After the cylinder leaves the foundry, it is taken to the machine shop, and bored out to make it perfectly cylindrical, the flanges faced, bolt-holes drilled, and valve face planed. The cylinder heads are then fitted up so as to make a steam-tight joint, and secured to the cylinder by bolts and nuts. Generally the *bottom* of the cylinder is cast with it; the top or head only being removable.

Ques. How is the steam-chest constructed?

Ans. Generally the steam-chest is cast on the cylinder, but as it is a most difficult matter to scrape and true up the seats, when it is cast on, it is better to cast it separately in the shape of a box, and secure it to the cylinder, by means of stud-bolts passing through both chest and cover, and securing both by nuts.

Ques. How are the valves made to work steam-tight on the valve-face?

Ans. Both the valve and the face are planed, and then filed and scraped until they touch at every point. By rubbing a little thin red lead over the face, and then sliding the valve over it, it can be seen at a glance whether they touch at all points or not, if they do not they must be scraped until they do.

Ques. Are not the cylinders, steam-chests, etc., covered to prevent a loss of heat by radiation?

Ans. They are first covered with thick hair felt, and then wooden staves, called lagging, are put over it, and secured by brass bands.

Ques. How is the piston-rod secured to the piston?

Ans. Sometimes by means of a key, but generally the rod passes through the piston, and it is secured by a nut.

Ques. How is the piston constructed?

Ans. It is made of cast-iron, and is cast in two pieces. The main body to which the piston-rod is attached is called the piston head or spider, the other part which is used to keep the packing rings in place is called the *follower*, and it is fastened to the spider by bolts called *follower-bolts*. These follower-bolts are generally made of composition but wrought iron ones are stronger and not so liable to be twisted off.

Ques. How is the piston made to work steam-tight in the cylinder?

Ans. By means of two cast-iron or brass rings called packing rings. These rings are turned a little larger than the diameter of the cylinders, and then cut diagonally so that they can be set out or expanded to fill the cylinder completely by steel springs set out by bolts.

The place where one ring is cut is placed opposite to that of the other, so as to break the joint. This is done to prevent the steam passing through one joint from passing through the other. There is another ring made of cast-iron, and as wide as both the others, placed on the inside, the latter to furnish a bearing for the springs and cause them to press equally against the outer rings. The inner ring is also cut.

Ques. How is the piston-rod made to work steam-tight through the cylinder?

Ans. By filling the stuffing-box with packing (see article on packing elsewhere) which is kept in place by the *gland.* Whenever the box leaks from wear of the packing it is made tight by screwing up the gland.

Ques. Is the piston-rod attached to the cross-head?

Ans. Sometimes the cross-head and piston-rod are forged together, but the general practice is to pass the piston-rod through a hole in the cross-head and secure it by a nut or key.

Ques. How are the piston and rod caused to work in a straight line?

Ans. By means of guides or slides to which the cross-head is attached by means of brass wearing-pieces called "gibs." When these gibs become much worn they are set out by means of thin pieces of metal called "liners," or by set screws.

Ques. How is the connecting-rod attached to the cross-head and crank-pin.

Ans. The ends of the rods have brass boxes which are made in pairs so as to embrace the pins from each side; they are secured in place by a strap, gib and key. The cross-head end of the connecting-rod is called the "fork-end," and the crank-pin end the "stub-end."

Ques. What is meant by lost motion?

Ans. Lost or loose motion is caused by the wear of the brasses and journals, and when this is prevented by means of keying-up or putting in liners, it is called "taking up the lost motion." All the rattling, and most of the disagreeable noises about an engine, are caused by lost motion.

Ques. Of what material is the poppet-valve of beam-engines made?

Ans. Both the valve and seats are made of brass or composition.

Ques. How are they made steam-tight?

Ans. By grinding them in with ground glass mixed with oil.

Ques. Is not the lining of the air-pump also made of brass?

Ans. Yes. It is sometimes put in the shape of staves hammered on the inside and afterwards bored out, but the general and best practice is to put the brass lining in in one piece. This is always done with the air-pump of screw engines. The air-pump piston is also made of brass. The valves are made of thick gum, resting on a grating and kept in place by a guard. The tubes of surface-condensers are also made of brass, and generally tinned on both sides.

Fig. 23 will give you at a glance the arrangement of the interior of a steam-chest with its slide-valve, steam and exhaust-ports; while within the cylinder can be seen the piston with its rings, rod, and follower. It also shows the packing in the stuffing-boxes, with glands set.

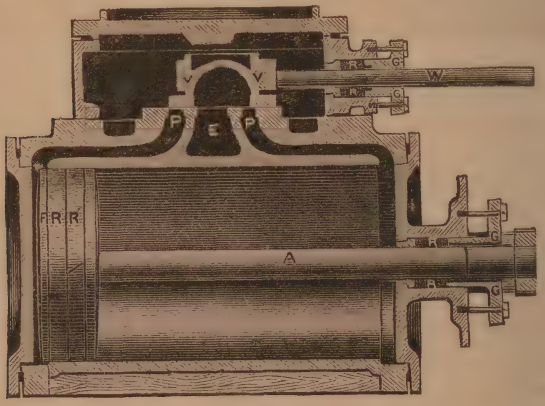


Fig. 23.

V V—Valve; *W*—Valve-stem; *P P*—Steam-ports; *E*—Exhaust-ports; *K*—Stuffing-boxes filled with packing; *A*—Piston-rod; *R R*—Piston rings; *F*—Follower; *G*—Glands.

LINK MOTION AND VALVE GEAR.

Ques. How is the valve gear of a screw engine constructed?

Ans. The valves of screw engines are now invariably worked by what is known as the "link motion." This consists of the forward

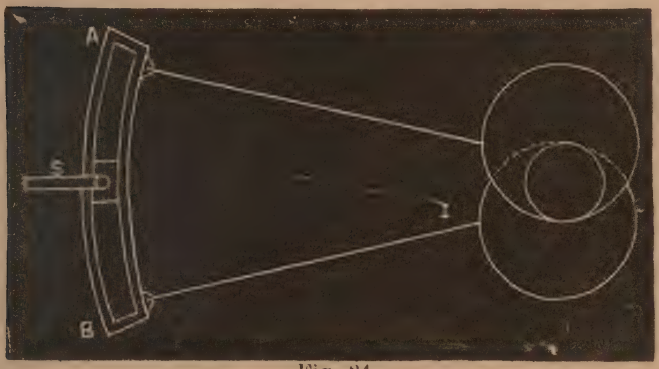


Fig. 24.

and backing eccentric-rods being connected together by a link with a curved slot in it, in which a pin, enclosed in a brass block, called the link block, works, and which is connected to the valve-stem. By moving the link so as to bring the forward eccentric-rod, A, in line with the valve-stem, S, the engine will go ahead; and by moving so as to bring the backing eccentric-rod, B, in line with the valve-stem, S, the engine will go back. The figure explains it all at a glance. The eccentrics are generally made of cast-iron, cast in two pieces and bolted together;

the rods and the link are made of wrought-iron.

LAP AND LEAD.

Ques. What is meant by the lap of a valve?

Ans. If the face of a valve just covered the steam-port it would have no lap, and as much as it exceeds the port is lap. For instance, if the port were one inch wide, and the valve-face 1 1-4 inches wide, then there would be 1-4 inch lap.

Ques. What is the object of putting lap on a valve?

Ans. To cut off the steam, which is called cutting off by lap.

Ques. If that can be done, then why have a separate or independent cut-off valve?

Ans. Because owing to the exhaust getting "cramped" the steam cannot be cut off at less than 2-3 of the stroke, therefore an independent cut off valve is necessary when it is desirable to cut off shorter, except when the valve is worked by link motion.

Ques. The link then can be used as a cut-off?

Ans. It can, and often is, still it is better to have an independent cut-off, even when the valve is worked by a link instead of a hook.

Ques. Why?

Ans. Because the link is more of a "squeeze-off" than a cut-off; it wiredraws the steam, by

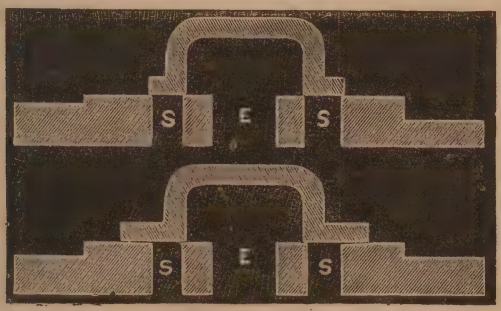
diminishing the opening of the port, and thereby lessening the power of the engine.

Ques. What is meant by lead?

Ans. Lead is the amount of opening the valve presents for the admission of steam at the beginning of the stroke.

Ques. What amount of lead do you consider sufficient?

Ans. 1-4 inch for all engines making more than 50 revolutions per minute; 1-8 inch for more than 25 and less than 50 revolutions per minute. Engines making less than 25 revolutions do not require any lead at all, and it is a mistake to give it; but in that case (if a beam engine with poppet-valves), the *exhaust*-valves should open just before the end of the stroke.



Figs. 25 and 26.

S S—Steam-port. *E*—Exhaust-port.

Fig. 25 shows a valve without lap which just covers the port. Fig. 26 shows a valve with lap.

STRAPS, GIBS, AND KEYS.

Ques. Will you explain the strap-ends of connecting and other rods?

Ans. In Fig. 27 is shown the simple form of a strap-end connecting-rod. It is a very convenient form to put up and take down, but, as the strap moves up the rod-end as the brasses are keyed together to take up the wear, it gets shorter, and there is no very ready method of showing how far the strap should be set back, nor where the centre of the bore of the brasses should stand to maintain the rod of its original length from centre to centre of the bore of the brasses. The result is that the length of the rod is apt to be altered when the slips of iron are put behind the brasses to set the key up. This alters the location of the piston-stroke in the cylinder, giving less clearance (between the piston-head when at the ends of its stroke, and the cylinder-cover) at one end and more at the other, sometimes causing the piston-head to strike the cylinder-cover. Furthermore, there sometimes exists at the ends of the cylinder a ridge of metal, caused by the piston-head not travelling from end to end of the cylinder bore, and by the wear of the cylinder, so that the diameter of the bore is not so great at the ends.

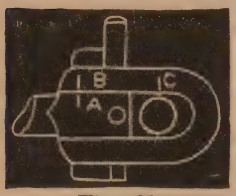


Fig. 27

Hence, when the location of the piston-stroke is altered, the piston will strike this ridge at one end and not meet it at the other end of the cylinder, wearing away the existing ridge at the first end, and increasing it at the last-named end. As a guide to avoid this, we may mark on the face of the rod-end a deep line, A, in the engraving, and a similar line, B, on the strap. Then another line, C, on the strap, and if in lining up the brasses to set the key back we make A and B come even, and the centre of the bore of the brasses come fairly beneath C, the rod will be kept of its original length so far as that end is concerned. If, in this kind of rod-end, the joint face of the two brasses butt tightly against each other when the brass bores are a proper fit to the crank-pin, we may drive the key tightly home, and the strap will be firmly locked by the key to the rod-end, so that the key and gib will not be subject to much wear. But, if the brasses are left open at the joint so as to be able to take up any lost motion (due to the wear) without filing the joint faces, the key cannot be driven home, because that would bind the brasses upon the journal; hence, in this case, the strap is not locked to the rod-end at all, but hangs (as it were) thereon. In this latter case the wear is many times greater because of the difficulty of adjusting the brasses so delicately as not to

have any lost motion (and therefore no thumping), and, at the same time, not to bear too hard against the journal.

In Fig. 28 is shown a bolted connecting-rod-end, A; B being the brasses, C a strap, and DE two bolts. This class of rod is used mainly on marine engines. Here we have no means of correcting the length, and great care must be taken to place behind the brass, A, a liner of the proper thickness, to compensate for the wear. In this case, however, there might be marked upon the rod a deep line, which should always stand at a known distance from the centre of the journal, that distance being marked beside the line as at F in the figure where it is marked as 4.

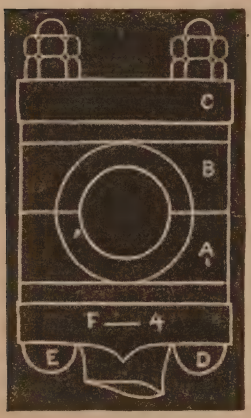


Fig. 28.

CHAPTER XVII.

STEAM AND VACUUM-GAUGES.

Ques. What kinds of steam and vacuum-gauges are generally used on marine engines?

Ans. Mercury gauges are seldom used at

Fig. 29.

present, but in their stead we have a number of excellent makes of metallic gauges both for steam and vacuum, among others there are Ashcroft's, Bourdin's, Schmidt's, American Steam Gauge Co.'s and Schaeffer's, all of which are well made and reliable. Fig. 29 represents

an Engine Register and Steam and Vacuum-gauge sold by W. C. Duyckinck, 50 John St., New York.

Ques. Should not every boiler have two steam-gauges attached to it?

Ans. As nothing made by human hands is perfect, steam-gauges form no exception to the rule, and therefore there should be two, so that one may act as a check upon the other. But they should each be attached to the boiler by a separate pipe, because if they are both fixed to one pipe and that gets stopped up both gauges will be in error.

Ques. Do not the pointers of steam and vacuum-gauges vibrate voilently sometimes, owing to the fluctuating pressure in the boiler or condenser while the engine is in motion?

Ans When they do so, turn the cock on the gauge off until the pointer remains *almost* stationary, otherwise the springs which are very delicate will be weakened, making the gauge unreliable.

Ques. Do not the pointers sometimes stick fast?

Ans. If they do, jar the gauge by slapping it with the hand so as to knock the pointers down.

VACUUM.

Ques. What is a vacuum?

Ans. A vacuum means an empty space.

Ques. How is a vacuum in a steam engine produced?

Ans. After the steam has done its work in the cylinder it is exhausted into the condenser, where it is condensed (turned into water again) by a shower of cold water; it then falls, in the shape of hot water, to the bottom of the condenser, and the *space* above the water in the condenser is a vacuum.

Ques. Is the vacuum in the condenser a perfect one?

Ans. No; as more or less vapor always follows the condensation of the steam, and besides a small quantity of air enters with the condensing water. When a vacuum-gauge shows more than 28 inches of vacuum, the gauge is out of order and unreliable; as 28 inches (30 inches being perfect) is about all that it is possible to obtain in a steam engine, assertions to the contrary notwithstanding.

BACK-PRESSURE.

Ques. What is meant by back-pressure?

Ans. As it is impossible in practice to obtain a perfect vacuum in the steam engine there is always more or less vapor opposed to the motion of the piston, and this is what is called back-pressure; it is the difference between a perfect

vacuum and that shown on the vacuum-gauge. Every two (2) inches of vacuum equal one (1) pound pressure.

GONGS, BELLS, ETC.

Ques. Are not gongs used to give signals to the engineer?

Ans. Yes. In the merchant service the signals are as follows: 1 bell, Go ahead slow; 1 bell, Stop; 2 bells, Back; jingle bell, Go ahead fast.

In the Navy the signals are as follows: 1 bell, Ahead slow; 2 bells, Stop; 3 bells, Back; 4 bells, Ahead fast. A jingle bell is not used.

The hammer of the gong should not rest upon the gong but stand off about 1-4 inch.

HOW TO READ THE COUNTER, OR REGISTER.

Ques. How do you ascertain the number of revolutions made per minute by the engine by the counter?

Ans. Note the figures on the counter at *any* time, and in one hour note them again; subtract the former from the latter, which will give the number per hour, which divided by 60 will give the number per minute. Example: Suppose your counter shows the number 1878, and at the end of the hour it shows 4878. Then—

4878
1878
60)3000=Per hour.
50=Per minute.

CHAPTER XVIII.

SURFACE-CONDENSERS.

Ques. What is a surface-condenser?

Ans. A surface-condenser is an instrument for condensing steam by contact with cold metallic surfaces instead of bringing it directly into contact with a shower of cold water, as done in a jet-condenser. The object of using such a condenser in lieu of the common jet is to furnish boilers of marine steamers with distilled instead of sea water, consequently to provide against the loss of fuel otherwise occasioned by blowing off a portion of the water to keep the concentration at a desired point. Also to prevent the loss due to the little conducting power of the envelope of scale which attaches to all heating surfaces of boilers using sea water. By the use of such an instrument there is also gained the saving in labor of scaling and cleaning the boilers which belongs to all sea steamers using the common jet, and this is of no small importance to those having the care of steam machinery. Again, by its use the expense of repairs to the boilers is considerably reduced, their durability greatly increased, the pressure of steam which can be judiciously carried is unlimited, and the expansion of the steam can be carried to a greater extent.

Ques. How are the tubes made tight?

Ans. By packing them with patent paper or wood packings, which leaves them free to expand and contract. The tubes should be made of brass, and be tinned both on the inside and the outside. Every surface-condenser should be so arranged as to convert into a jet-condenser, should the necessity for so doing arise.

CONDENSER GETTING HOT.

Ques. What is meant by the condenser getting hot?

Ans. When the engines are standing still it sometimes occurs that the condenser gets so hot that when it becomes necessary to start again the pressure has become so great in it, that the injection water will not enter. Leaky steam and exhaust-valves will alone cause this, but in no case should it ever be allowed to occur. When a condenser begins to get hot the cracking noise in it and about the foot-valves will always indicate what is going on in time enough to check it, which can be done by giving a little injection and causing the engines to make two or three revolutions back and forth. If, however, the engine should become too hot to take the injection water, the only plan will be to blow through or pump water into the condenser or air-pump, if there be such an arrangement, or to cool the condenser by the external application of cold water.

This relates to *jet*-condensers, as in case of

surface-condensers, the condensing water is *forced* through, and there need be no trouble about the condenser getting hot.

HOT-WELL.

Ques. Are not thermometers sometimes attached to the hot-well?

Ans. Every marine engine should have a thermometer attached to the hot-well, to ascertain the temperature of the water which should be carried at from 100 ° to 112 ° Fahr. A thermometer is an important instrument in such a position, for it may often occur that there may start small leaks about the condenser or exhaust-pipes, which would cause a decrease in the vacuum, and as without the thermometer, the first impulse would be to give more injection water, with it we would turn our attention to finding the air leak, which could be done by holding a hand lamp or candle around the joints. Wherever there is a leak the light will be drawn in. When found, stop with white and red lead putty.

CHAPTER XIX.

SEA VALVES AND COCKS.

Ques. Should not all sea cocks, valves, etc., be placed so that the engineer can see them at all times?

Ans. It is well known that all the water from the sea required for the purpose of working the engines and boilers of the vessel is admitted through several holes cut through the bottom or bilge, and that those holes are covered by what is known as sea valves or cocks, made either of cast-iron or brass, and that they are secured to the skin of the vessel by bolts and connected to the engines and boilers by pipes of copper, brass, or iron. Heretofore these valves or cocks have generally been placed low down on the floor, so as to be out of the way. The engine room as well as the fire room floor plates being above them, they are out of sight, and very difficult of access, so that if a leak or accident occurs it is not always discovered until the water rises to the floor, when it may be too late, for the engineer cannot ascertain the cause in consequence of the valves and pipes being covered with a considerable depth of water. Many serious accidents have happened in consequence of this arrangement. Among them may be mentioned the loss of the *Knight Templar;* also the case of the French trans-Atlantic steamer *Europe*, of 4,000 tons, abandoned in the Atlantic, April 2d, 1874, the crew and passengers, in all about four hundred, being taken off the sinking vessel by the English steamer *Greece.* When abandoned there were only about six feet of water in the engine and

fire-rooms, and one foot in the adjoining holds. It is evident that the leak was in the engine department, from sea connections, as was proved by a very singular coincidence, for only a few days afterward her sister ship, the *Amerique*, of 4,000 tons, belonging to the same owners, was abandoned in the English channel, afterward picked up by an English steamer, and towed into Plymouth Harbor with the engine and boiler rooms full of water. When it was pumped out nothing was found wrong with the ship, and the difficulty with the sea-connections was never made public. These two ships were valued at nearly $3,888,000, exclusive of cargoes, and their abandonment at sea under such circumstances was altogether owing to the want of practical engineering skill and courage, added to the captain's lack of presence of mind in emergencies.

CHAPTER XX.

DONKEY PUMPS.

Ques. For what purposes are steam or donkey pumps used?

Ans. Steam-pumps should be fitted with all the necessary pipes, cocks, and valves, and be arranged for use as a fire engine, for washing down the decks, to feed the boiler from the hot-

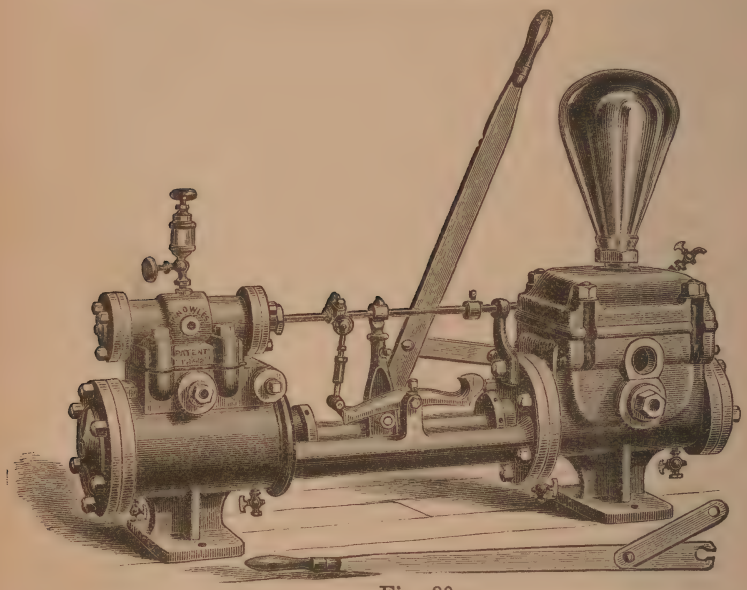


Fig. 30.

well or the sea, and to pump from the bilge, and be fitted with a double exhaust connection, to exhaust either into the condenser or the atmosphere. It should be provided with one hundred feet of rubber hose in two lengths with reel, couplings, and one brass and one leather nozzle-pipe. All the water-pipes should be of copper, the steam and exhaust-pipes of wrought-iron. Fig. 30 shows a Knowles steam-pump which has few equals, if any, and no superior.

Ques. Does it not injure a boiler to pump cold water into it from the sea with the donkey pump?

Ans. It does, and in old boilers it almost invariably causes the patches, plugs, and seams to leak, and it should not be used for boiler feed if it can be helped. Some engineers practise pumping cold water into their boilers to kill the steam or prevent blowing off at the safety-valve, which is most injurious. Injectors throwing hot water are now coming into use on steam vessels as boiler feeders, which is a long step in the right direction. Every boiler should be provided with them.

INJECTION-PIPES.

There should be three injection-pipes attached to the condenser, side, bottom, and bilge. Use the bottom injection when running in deep water, or when the vessel is rolling heavily; the side when in shoal water, because if the bottom should then be used, the water will carry dirt, sand, etc., in with it, to the manifest injury of condenser, air-pump, and feed-pumps.

Ques. When should the bilge injection be used?

Ans. Only in cases of great emergency, to prevent the ship from sinking, or to help the bilge-pump to keep the water down when that cannot do it alone. The mouth of the pipe should be enclosed in a box-shaped strainer, made of *lead*, punched full of *small* holes to keep out chips, coal, dirt and other impuri-

ties usually found in the bilge, otherwise it will choke.

Ques. When the condenser is a surface-condenser should not the circulating-pump have a branch pipe on its suction side leading to the bilge?

Ans. Yes; and the valve or cock ought to be locked, so that it can only be opened by the chief-engineer. Bilge injections must only be used when all other means fail to keep the water out of the ship.

CHAPTER XXI.

COMPOUND ENGINES.

Ques. What is a compound engine.

Ans. A compound engine is one in which a high-pressure engine is combined with a low-pressure engine. The steam is admitted first into the small, or high-pressure cylinder, and then instead of being exhausted into the condenser, it goes into the larger, or low-pressure cylinder, and then to the condenser. The object in having one cylinder larger than the other is to cause them to develop the same power. Any engineer who understands the simple engine will have no difficulty in the managament of the compound. In some

compound engines, the steam is exhausted from the small cylinder directly into the larger, while in others it passes through a "receiver," a kind of steam-reservoir. A given amount of steam *ought* to develop a given amount of power, whether it be used in one cylinder or fifty, and for this reason some engineers maintain that a long stroke single engine is as economical as a compound engine, but experience, which is our only teacher, proves quite the contrary. The best designed and constructed steam engine is far from being a perfect machine, and therefore theoretical results cannot be attained in practice. Chief-Engineer J. W. King, in his official report to the Secretary of the Navy, speaks as follows upon the subject of compound engines:—

"The efforts of the engineering profession have long been directed to the reduction of the cost of the production of power, and for a lenghtened period the question of the relative merits of the simple and compound engines occupied the attention of the engineering world. Many experiments have been made, and much ability and ingenuity displayed, to prove that the compound system possessed no advantages over the ordinary simple engine working high-pressure steam; the most important of these experiments will be noticed presently.

"My annual report to the Department, as

Chief of the Bureau of Steam-Engineering, dated October 30, 1871, just after returning from a short tour of investigation of the subject, gives the facts at that time; and as they hold good to-day, I cannot do better than copy that part of the report which bears on the subject. It is as follows:

"'The tour proved very instructive and interesting in many respects, especially in Great Britain, where immense fleets of iron ships are constructed and put afloat yearly, where ships are built for nearly all European nations, and where the British Navy is systematically improved and strengthened by additions of nearly twenty thousand tons of iron-clads annually, besides transports and unarmored vessels.

"'The vast and varied experience of their constructing engineers, and the sharp competition between rival building firms have given rise to rapid improvements, and compelled the abandonment of many designs only a few years ago regarded as the best productions of engineering skill.

"'The pressure of steam carried in marine boilers has gradually risen with corresponding increase in the extent to which expansion is carried, until boilers have been introduced, and are coming into universal use on board ship, in which the steam is kept from sixty to seventy-five pounds per square inch,

and expanded in the cylinders from ten to fourteen times.

"'The form of boiler used for generating the steam differs from the variety so long employed in all European steamers. It is built with a cylindrical shell of from 9 to 15 feet diameter, and of thickness from 3-4 inch to 1 1-4 inches, according to the pressure to be carried. It is sometimes from 9 to 10 feet long, and is placed in the vessel athwartships, with fire-rooms fore and aft in the ordinary way, and sometimes about 18 feet long, placed fore and aft, and fired from either end. There are two or three cylindrical flues, according to diameter, in which are the grates, and above them a set of horizontal fire-tubes, through which the gases return to the front, thence to the funnel. This boiler is strong, of moderate cost, and generates steam freely and economically.

"'The type of engine employed for working the steam is known as double-expansion, or compound, the steam being admitted from the boilers first into a small high-pressure cylinder, there expanded to a third or fourth of its original pressure, then passed through a receiver into a large or low-pressure cylinder, where, after propelling the piston to the end of the stroke, it is exhausted into the condenser. This system of working steam expansively was introduced by Woolf seventy years ago; but

at that date steam was used at a very low pressure, and the project met with no success. For many succeeding years the subject was discussed and experimented upon by engineers, but no advantages over the ordinary method of working steam expansively in a single cylinder were reached, until a talented engineer of Scotland, Mr. John Elder, proprietor of the Fairfield Works, near Glasgow, several years ago took up the subject, and, in the face of immense opposition, zealously pursued it, designing and constructing every year several sets, each being more and more improved in design and detail, until they have been brought to the present state of perfection.

"'Of the thirty-seven engineering works and iron ship building yards on the Clyde, the Fairfield Works is now the most extensive and important. At the time of my visit this firm had already completed one hundred and thirty pairs of marine compound engines, and accompanying boilers, and had then twenty-two pairs under construction—all for ocean-steamers; besides, in their ship-yard, ten large iron vessels were on the blocks, four at the wharf, being engined and completed, and orders were on hand for others as soon as room could be made for them. This firm is justly regarded as the pioneer of the compound system, and their productions are accepted as the best types.

"'The largest establishment on the river Tyne, "and, as a combination of engineering and manufacturing," the most extensive in Great Britain, the Palmer Company, had under construction about the same number of compound engines, two iron-clads for the British navy, and several other vessels. In short, all engineering-works in Great Britain are now building their marine steam machinery on the new system. These engines are also manufactured by Messrs. Schneider & Co., at Crenzot, and M. Mazeline, at Havre, France. They are also built in Germany and in Belgium Indeed, the success of the system is so certainly established that no European owner will now contract for an ocean steamer unless it is stipulated that she shall be propelled by compound machinery.

"'Many commercial vessels containing very good machinery of the ordinary kind have been laid up, the machinery removed, and other machinery, on the new system, substituted. An example of this came under my notice in the case of one of the West India mail screw steamers—the *Tasmania*. This vessel, twelve years old, had the best machinery, with jet-condenser, at the date of construction; with it fifty round trips had been made, all the machinery was then removed, and compound machinery substituted. At the date of my visit

one round trip had been made with it, and an inspection of the logs showed the average consumption of coal for the round trip with the old machinery to be three thousand tons, while the round trip with new machinery had been made with fourteen hundred and forty-five tons, the speed of vessel remaining the same. In some cases such as that of the *Ville de Paris* and *Periere*, of the French Atlantic line, both comparatively new ships, and having excellent machinery, orders have been issued for its conversion by the addition of a third steam-cylinder, to be used for the admission of the high-pressure steam, the removal of the present boilers, and in lieu thereof high-pressure ones placed on board.

"'The Cunard Company, the most conservative of all steamship owners, who were the last of the companies to substitute iron vessels for wooden vessels, who were the last to give up the paddle-wheels for the screw, are now the last to accept the compound engine and high-pressure steam in the vessels of their line in lieu of the old system. But in this, as in former cases, sharp competition of several lines has caused this company to convert the machinery of one of their vessels, and to place the new type in two small vessels, the *Batavia* and *Parthia;* besides, at the time of my visit,

the models were being prepared for two vessels of dimensions larger than any now on the line, to be constructed and supplied with the compound type of machinery.*

"'The British Admiralty, charged with the administration of by far the largest and most powerful navy in the world, always cautious in the application of new inventions, rarely adopting any untried plans, but surely accepting the most successful in practical operation, have in this particular made the test of the new system by its application to two ordinary wooden vessels, the *Tenedos* and the *Briton*, of 1,331 and 1,261 tons register, respectively. The success attending the trials of these two vessels justified them in ordering the third set for the *Thetis;* also two other sets for the twin-screw iron clads *Hydra* and *Cyclops*, all now under construction; and although several iron-clads and unarmored vessels are being completed with the ordinary type of screw-machinery, ordered two or more years ago, all future ships constructed for the British navy will doubtless be engined on the new system. It is not probable, however, that any of their six hundred registered vessels will be ordered to undergo the process of alteration, because their cruising steamers are intended to

* These two ships, since completed, are the *Bothnia* and *Scythia*.

be essentially sailing vessels, and their steam power is only used when the sails cannot be depended upon to accomplish the purpose required; the cost, therefore, of the alteration from the old to the new machinery would be too great for the results desired to be obtained.

"'The original cost of steam machinery on the compound system, its total weight, and the space occupied by it in a vessel, does not materially differ from that of the ordinary type. The advantages are chiefly in the reduced consumption of fuel, less space for it on board, and smaller number of men required to handle it. These advantages have been found very great in commercial vessels making long passages, so great that the new type of machinery is as surely displacing the old on the ocean as the screw displaced the paddle, and surface-condensation displaced the old jet-condenser. In the two steamers of the British royal navy to which the compound engines have been applied and tested, and in the Atlantic steamers plying between New York and Liverpool, having this kind of machinery on board, the power developed is obtained with less than two pounds of good English coal per horse-power per hour, or half the fuel for the same power developed under the system of non-expansion and jet-condensation. In other words, a steamer is propelled

the same distance, and at the same speed, by compound machinery, with five hundred tons of coal, that required one thousand tons with the old type, and from thirty to forty per centum less than with the latest and best kind, having surface-condensation and superheaters.

"'The progress made in this direction, of economy in fuel, may be briefly noted in the following facts: The paddle-wheel steamer *Scotia*, of the Cunard line, put afloat in 1862, and at the date regarded as the best and latest type of engineering skill, a vessel having a midship section of 841 square feet, consumed 160 tons of coal per day, or 1,600 tons on the ten days' passage between New York and Liverpool. The *City of Brussels*, a screw-steamer of the Inman line, put afloat in 1869, and having a midship section of 709 square feet, consumed 95 tons per day, or 950 tons on the ten days' passage. The *Spain*, a screw-steamer of the National line, put afloat in 1871, with compound machinery, and the largest ship on the Atlantic, having a length of 425 feet 6 inches on the load-line, beam molded 43 feet, draught, loaded, 24 feet 9 inches, made the passage in September with 53 tons of coal per day, or 530 tons on the ten days' run; all three vessels having the same average speed; a small percentage only of the gain being due to the finer lines and proportions of the last-constructed vessels.

"'The field of observations in this direction has been thoroughly gone over, the subject carefully investigated, and the Bureau is informed of the extent of European operations and results, of which a brief outline has been given. The information is positive, and there can be no hesitation in recommending that all cruising steamers for the Navy hereafter put afloat be engined on the compound system, and that all the steam-machinery stored in the navy-yards that cannot be used to advantage in the old vessels, or converted into compound, be disposed of by public sale, or broken up and used as old material; and in view of the necessity of timely preparation, the Bureau has taken steps for the execution of complete sets of working-drawings for machinery of vessels on the stocks, and that will suit classes of vessels that may be designed as cruisers. It is not, however, recommended to remove the machinery from any of the old vessels for the purpose of replacing it by the new, except in cases where the repairs to the old shall be found so costly as to condemn it altogether; for the appropriations are desired to be as small as compatible with the public interest, and the cost of alteration would be too great, considering the advantages desired to be gained under the regulations, of using sails as the motive power, except in cases of emergencies.'

"Subsequent experience has still more firmly established the compound system. In European nations simple expansion engines for all commercial and naval vessels are now as obsolete as the paddle-wheel on the ocean. The records of the surveyor's office in London show that of the several hundred commercial sea-going vessels built in the kingdom since 1871, including one hundred and twenty-three under construction when the report of this last year was received, all, excepting a very few for special purposes, have been engined on the compound system. Besides this, a large number of steamers set afloat previous to the successful application of the compound engine on the ocean, have, since my last report, been docked, the engines and boilers removed to the scrap-heap, and in lieu thereof compound machinery erected on board; a number of the vessels having the machinery so altered not being more than eight years old, and some only five years old. The steamers of the commercial fleet of Great Britain still retaining the old types of engines and boilers, retain them because the vessels cannot be spared from employment sufficiently long to remove the old machinery and substitute the new, or because the vessels are not worth the expense of the change. So far has this system of compounding the machinery of old vessels been carried,

or, more properly, of substituting the compound for the simple type, that for vessels of 1,000 tons and under, the proprietors of several engineering works have built in anticipation, and retained on hand to a considerable extent, compound engines and accompanying boilers suitable for vessels probably requiring them, and in many cases they have contracted for and accomplished the feat of removing the old machinery and erecting on board the new in ten days' time. Many of the old channel, coast, and river steamers of England still retain their old machinery, for the reasons above stated. Some, however, have been altered; one of them a paddle-steamer, the *Wolf*, in which I chanced to make a passage from Harve to Southampton. This vessel has a length of 250 feet, breadth 27 feet, and draws 9 feet of water. She was furnished originally with the old type of inclined engines, jet-condensers, and box-boilers, carrying 30 pounds pressure of steam. For eight years she made the passage regularly between Harve and Southampton, of eighteen hours, on 48 tons of coal for the round trip. Two years ago these engines were compounded, and cylindrical boilers, carrying 60 pounds pressure of steam, substituted for the old ones. The results of this change were increased speed, and an average consumption of coal for each round trip of 28

tons. Many other cases could be cited, but it is believed to be sufficient to state that Lloyd's inspecting-engineer's books show the saving of fuel resulting from compounding engines of British steamers to be from 30 to 40 per cent.

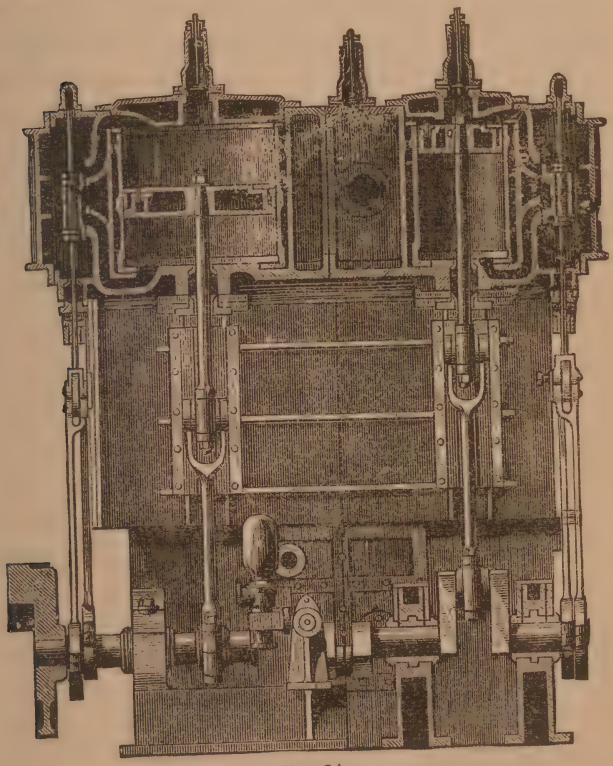


Fig. 31.

Vertical Inverted Direct-acting Compound Engines (Screw Steamers.)

"One of the steamship companies visited, having steamers that make long passages, was the Royal Mail. This company owns twenty-four steamers, eighteen of which are engined on the compound system, three still retain the old type of engines, and three have been altered from the old to the new system, with an average gain in fuel of 40 per cent. The *Moselle*, a vessel of this line, to which my attention was called as one economical in fuel, has a length of 376 feet, breadth of 40 feet, and a draught of water of 21 feet. She was built by Elder & Co., in 1873. The engines are of the inverted vertical compound type, with a high-pressure cylinder of 60 1-2 inches, and low-pressure of 112 inches in diameter, having a stroke of 4 feet. The boilers are cylindrical, and the pressure of steam 60 pounds to the square inch. This vessel is on the West India line; the distance steamed for each round voyage is 10,000 miles, the average speed 12 knots, and the average consumption of coal 40 tons per day of 24 hours."

CHAPTER XXII.

STEAM ENGINE INDICATOR.

Ques. Should not every marine engineer be

, amiliar with the indicator, and know how to read its card?

Ans. The indicator is to the engineer what the stethoscope is to the physician; it reveals by its card or diagram the entire internal working of the engine. The following cuts, with description of the same by Paul Stillman,* late of the "Novelty Iron Works," will enable you to understand it. Every man calling himself a marine engineer, ought to understand the use of this most invaluable instrument, as it will enable him to detect defects in the working of his engine which he can discover by no other means.

USE OF THE INSTRUMENT.

The design of the steam engine indicator is to enable those who make, use, or have the charge of steam engines, to ascertain, at any moment desired, the condition of the parts of the engine subject to the direct action of the steam, and to what advantage the steam is applied. Its indications are automatically drawn on paper, and by the form of the diagram which it makes may be known the following particulars, viz. :

1st. Whether the valves are properly constructed and set, and if the steam passages, or ports, are of proper size to receive and discharge the steam in time to produce the best effect.

* The Steam-Engine Indicator,—and the Improved Manometer Steam and Vacuum Guages; their utility and application. By Paul Stillman. New York, D. Van Nostrand.

2d. What pressure of steam there is upon the piston at every position in the cylinder, as well as its average during the stroke.

3d. What is the value of the vacuum acting upon the piston of a condensing engine in all its positions in the cylinder, and what is its average.

4th. Whether the exhaust passage from the cylinder of a non-condensing engine is sufficiently large to give a free exit to the steam, and if not, what percentage of power is lost in forcibly expelling it.

5th. The actual consumption of steam in giving motion to the engine, and also what additional steam is used in giving motion to the shafting and mill work ; and then what power is required to give the requisite motion to the machinery, or to any part of it, provided it offers sufficient resistance to form any measurable proportion of the power of the engine. It will therefore indicate, at any time, or under any particular condition, the actual power of the engine.

6th. It will demonstrate the degree of economy in using steam of high-pressure and the use of expansion, and also the relative efficiency, of different kinds of expansion apparatus.

If applied also to the air-pump of condensing engines, it will give the data by which to de-

termine the quantity of water that would, under the circumstances, be most economically used in the condensation of the steam, or it may be advantageously applied to other pumps, when they do not work efficiently, to discover the nature or extent of defects or derangements.

The indicator, therefore, is an invaluable appendage to the steam engine, and where successfully applied can scarcely be too highly estimated.

DESCRIPTION OF THE INDICATOR.

The principle and action of the indicator are so simple, and, to most practical engineers now so well-known, that they will need but little particular description here. Some persons, however, into whose hands this treatise may fall, will perhaps be entirely unacquainted with the instrument. To such the following cut and explanation will give an idea of its construction.

A is a brass case inclosing a cylinder, into which a piston is nicely fitted. To the piston-rod a spiral spring is attached to resist the steam and vacuum when acting against it. B is a pencil attached to the piston-rod. C is an arm attached to the case, and supporting a cylinder, D, which may be caused to rotate back and forth—a part of a revolution in one direction, by means of an line or cord, e, attached to a suitable part of the engine—and in the other by means of a strong watch-spring

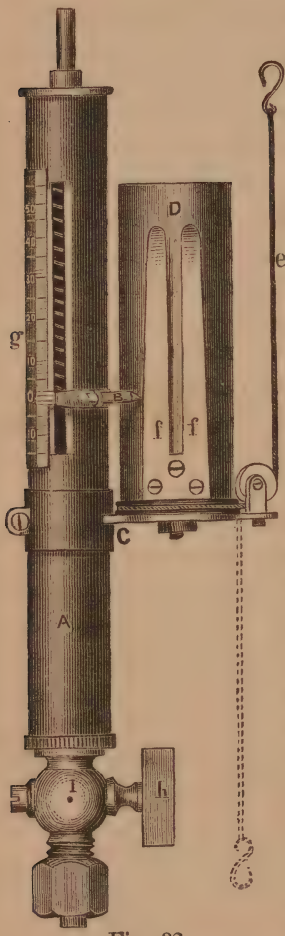


Fig. 32.

within this cylinder, D. Outside this cylinder is to be wound a paper, upon which a diagram will be made, by the combined action of the piston and paper cylinder, representing by its area the power exerted on one side of the piston during the whole revolution of the engine; ff are springs to secure the paper cylinder; g is a scale divided into parts corresponding to the pounds of pressure on the square inch. These divisions, for convenience of measuring the diagrams with a common rule, are generally made in some regular parts of an inch, as 8ths. 10ths, 12ths, 20ths, 30ths; h is a cock, by means of and through which it is connected with the engine cylinder.

HOW TO ATTACH THE INDICATOR.

Into whatever part of the engine it may be

desired to apply the indicator, there must first be inserted a small stop-cock, with a socket to receive the one connected with the indicator. The instrument is to be set into this in such a position that the line attached to the paper cylinder shall lead through or over the guide pully toward the place whence it is to receive its motion. An extension of this line should be connected with some part of the engine, the motion of which is coincident with that of the piston, and which would give the paper cylinder a motion of about three-fourths of a revolution. If the engine is of the construction denominated *beam* or *lever* engine, and is provided with a "parallel motion," the parallel bar, or a pulley, or the radius shaft, furnishes the proper motion; if otherwise, the beam centre may be resorted to. In the kind denominated *square* engines, the centre of the air-pump gives it. In horizontal and vertical *direct acting* engines, it will frequently be found necessary to erect a temporary rock-shaft, or lever, connecting with the cross-head. Particular care should be taken, when the power of the engine is to be estimated, that the motion communicated be perfectly coincident with that of the piston.

In nearly all forms of the steam engine, compound as well as simple ones, the proper motion may be obtained by attaching a line to the

cross-head, and passing it over a delicately constructed pulley, to the axis of which should be attached a smaller one, from which a line shall connect with the indicator. The proportional sizes of the two pulleys, of course, should be as the distance travelled by the piston to the length of motion given to the paper cylinder of the indicator. It will be necessary to attach a strong spring to the axis of these pulleys, to produce the reverse motion promptly. In an oscillating engine, it will be necessary that the indicator with its fixtures should be attached to the cylinder.

As the paper cylinder cannot make more than about three-fourths of a revolution without disturbing the point of the pencil, it will be seen that the line communicating the motion must be of a definite length. It also requires to be readily connected and disconnected. To meet these demands, one end should be provided with a running loop,* and the other with a hook.

* Provide a piece of metal about an inch long, one-sixth wide, and half as thick, and divide it equally by four holes. Through this reeve the line, as here represented, and you have a very convenient

RUNNING LOOP.

Fig. 33

When the indicator is to be attached to the lower end of a vertical cylinder, or to a horizontal one, it may be worked horizontally; but it is better to avoid such a position by the use of an angular attachment to the cocks.

TO TAKE A DIAGRAM.

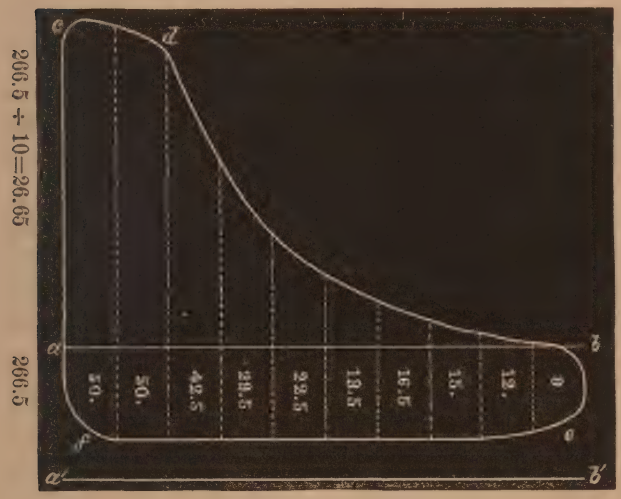


Fig. 34.

When the indicator and line are satisfactorily arranged, the pencil holder should be provided with a hard and well-pointed pencil. Regulate the bearing of this pencil by sliding it farther in or out of the holder; or by moving the paper cylinder forward or backward, so that it shall bear very lightly upon the paper.

Arrange the motion of the paper cylinder, by means of the running loop, so that it shall not be checked at one end by contact with its stop fixture, nor at the other by the paper springs coming in contact with the pencil, either of which occurring would alter the shape of the diagram. Lift off the movable part of paper cylinder, and affix the paper, upon which the diagram is to be made. The most ready method of doing this is to secure one corner of the paper by one spring; then, bending it around the cylinder, enter the other between the springs, and, clasping the hand around it, slide the whole down, taking care to leave it smooth and tight. The cylinder should then be restored to its place. The cocks may now be opened, to admit the steam to expand the cylinder and piston, and to see if its motion be free. When all is satisfactory, close the cock, and bend the pencil to the paper, and it will trace the atmospheric line, represented in the diagram by the line *a b*. Then, with the hand, press the piston down until the index is at 15 below 0 on the scale of lbs.—or, more exactly, to the figure agreeing with the existing state of the barometer—and let it trace the similar line *a′ b′*, representing perfect vacuum. Let it be supposed that the diagram to be taken be from the top of the cylinder of a condensing engine, worked by a slide steam-valve, and

provided also with a cut-off valve. Now, if the cocks be again opened, just as the piston begins to descend, the pencil will pass in a nearly direct line to *c*, and then, as the cylinder or paper revolves, the line *c d* will be drawn. At *d* the ingress of the steam is stopped by the cut-off valve, and the remainder of the stroke is performed by the expansive force of the steam, which produces the curved line *d b*. At *b* the exhaust-valve opens, and produces the exhaust line *b e*. The backward motion of the paper then produces the vacuum line *e f*. At *f* the exhaust-valve closes, and the remaining vapor begins to be compressed by the piston, producing the curved line *f a*, and upon the steam the effect called cushioning. Thus the pencil will have circumscribed on the paper a figure, the form of which exactly indicates the force exerted upon one side of the piston of the engine at every part of the stroke. The pencil should now be bent backward, the cock shut, and the diagram removed. The cord may be disengaged when most convienent.

For the convenience of describing these diagrams, their several parts will be designated as follows:—

The line from *a'* to *b*, the atmospheric line.
" " " *a* to *b'*, perfect vacuum line.
" " " *a* to *c*, receiving line.
" " " *c* to *d*, steam line.

The line from *d* to *b*, line or curve of expansion.

The line from *b* to *e*, exhaust line.

" " " *e* to *f*, vacuum or exhaust line.

The line from *f* to *a*, lead or cushion line.

In non-condensing engines, there being no vacuum, the line from *b* to *f* inclusive will be considered as the exhaust.

It should be borne in mind, that the extreme end or point of the diagram is produced at the *exact time* the *engine is passing its centre.* Thus it will be perceived, that the steam was in this instance admitted to the piston while the crank was on or passing one centre, and was exhausted before it reached the other, which it passed with a vacuum under it of about six pounds. It will often, and perhaps most generally, be found that two diagrams, taken at the different ends of the cylinder, will in some respects be dissimilar. In estimating the power of the engine, it is proper that this difference should be known, and the average of the two taken. It frequently happens, that several diagrams are taken from an engine at or near the same time, but from a different place, or under some different arrangement. Therefore, to avoid mistakes, and to make it more intelligible, immediately upon its removal from the indicator a note should be made

upon the margin, naming the engine, and stating the time and circumstances under which it was taken, with the height of steam, the labor it was doing, its vacuum by mercury gauge, the height of mercury in barometer, heat of water in condenser, etc.

For the purpose of ascertaining the *condition* of the valves, piston, etc., it will, in the hand of an experienced engineer, be quite sufficient for him to see the general outline of the diagram; but if it is to be used for ascertaining the power of the engine, its average measurement is to be ascertained. This will best be done by dividing it by a series of equi-distant vertical lines, and marking in each division its average measurement, as in figure 34. A division into 10 parts will generally be found most convenient; but for extreme accuracy, double the number may be required. The sum total of these measurements, divided by the number of them, will give the average or *effective* pressure per inch upon the piston. For all diagrams taken from non-condensing engines, and for others where only the effective pressure is sought, this manner of measurement is all that is required.

A more beautiful method of dividing and marking the diagrams, and one which might well be pursued where the diagram is to be given or transmitted to a person who has not

access to the scale of the instrument, is to draw, in different colored ink, another series of lines, parallel to the 0 line, and at a distances agreeing with and numbered according to the scale of lbs. on the indicator, in the following manner:

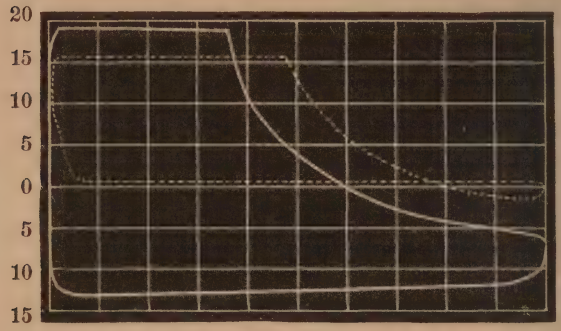


Fig. 35.

So arranged, the eye as readily comprehends their measurement as if the figures were written upon them, while their general character is still more readily observed. Sometimes it is desirable to find the value of the steam and vacuum pressure separately. To do this, it is necessary to measure from the 0 line upwards for the steam, and downwards for the vacuum. But in using steam expansively, it is common for the steam to expand until the line of expansion crosses the atmospheric line. In this case, the steam and expansion lines are to be measured from so long as any part of them re-

mains above 0. When it goes below, it forms the upper boundary of the vacuum, as in Figure 36.

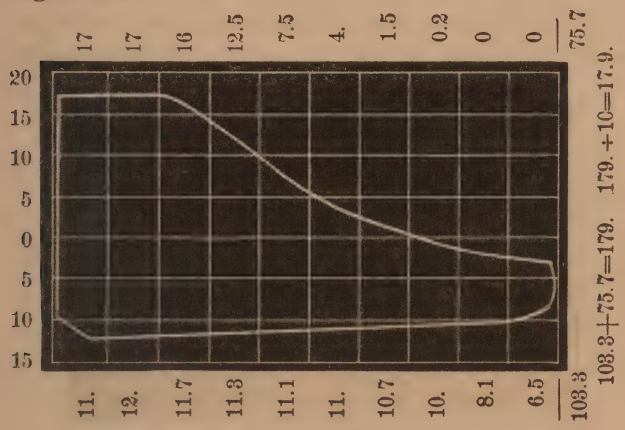


Fig. 36.

The pressure of steam is frequently, and most correctly, measured from the line of perfect vacuum. In such case the atmospheric line would be counted the 15th, and the vacuum 0. Where this mode is used, the diagram should be marked as in Figure 37.

In this case it is necessary to deduct as resistance from the sum of the pressures indicated by the steam and expansion line (measured from zero), the sum of the measurements between the 0 and the vacuum lines, and divide as before. A diagram from a non-condensing engine should be measured in a similar manner

—*zero*, however, being at atmospheric pressure. In Fig. 37, the steam or expansion line falls below the zero. In such cases, the space between the expansion and 0 lines is to be regarded as measuring the direct pressure, and all below the 0, together with all between it

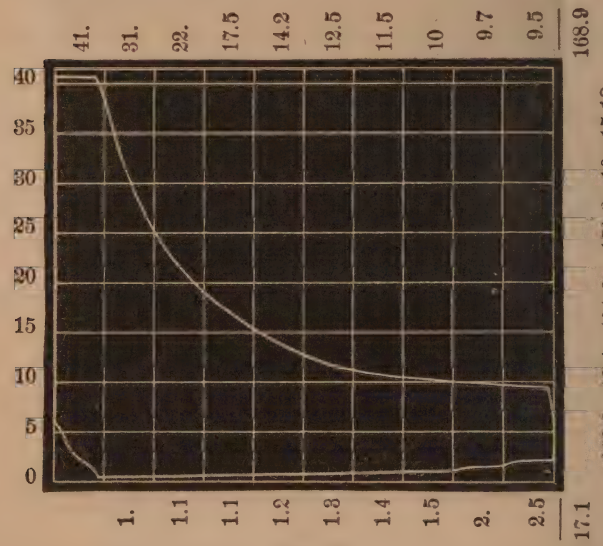


Fig. 37.

and the exhaust, as resistance. To ascertain the amount of steam used in giving motion to the machinery, without having regard to the condition of the engine, it is sufficient to measure the space between the steam and vacuum lines, as in Fig. 38.

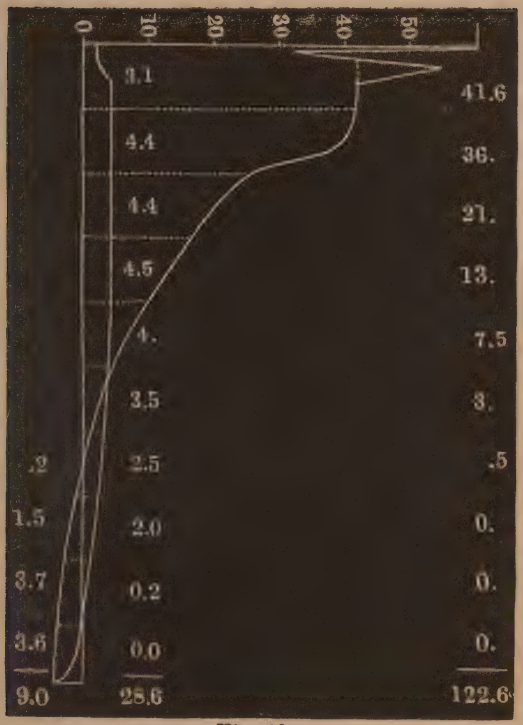


Fig. 38.

In designating the quality of vacuum formed under the piston, there are two elements affecting it, which ought to be noticed, viz., the weight of the atmosphere, and temperature of the water in the condenser at the time the diagram was made. For, if the barometer stands at only 28 inches, 30″ of mercury being equivalent to 14.7 pounds, 13.7 pounds would be a

perfect vacuum ; and if the water in the condenser be at a temperature of 130°, its vapor will form a resistance of 2.17 pounds ; therefore, the lowest attainable vacuum would be but 13.7—2.17=11.53 pounds ; whereas, if the barometer stood at 31″, a perfect vacuum would be 15.2 ; and if the water was but 100°, its vapor would give a resistance of only .9, and consequently the highest attainable vacuum would be 15.2—.9=14.3 pounds, making a difference of 2.77 pounds.*

When steam is used expansively, either in condensing or non-condensing engines, the line produced from the point where the expansion valve closes to the end of the stroke, if the valve is properly constructed, and the cylinder sufficiently protected or *jacketed*, should be nearly a hyperbolic curve, and may be thus described : Let an area be supposed equal to the longitudinal section of the cylinder, which, for the present purpose may be 10 feet=120 inches by 80. Let this be divided transversely into 10 sections. Now, if the steam used has an elastic force of 25 pounds above the atmosphere, it will, with the 15 pounds of the atmosphere, be equal to 40 pounds ; and if freely admitted to the cylinder for a distance equal to one of the above divisions, and then

* The vacuum shown by the Indicator will generally vary from that shown by the vacuum-gauge, when it is constructed with a glass tube.

shut off, and the piston allowed to continue its motion to another of the divisions, the pressure of steam will be reduced one-half ; and if its motion be continued to the fourth section, it will be reduced to one-fourth of its original pressure; if to the eighth, to one-eighth ; and so on, reducing the pressure of steam one-half as often as the piston travels a distance equal to the whole of its previous movement. Now, if a line be drawn truly through these several points, it will represent the curve due to such a proportion of cut-off ; and the area described will give the average pressure exerted by the steam during the stroke. Figure 38 represents such a curve, and also such other curves as would have been described had the steam been cut off at either of the other sections.

The figures at the right show to what pressure the steam would be reduced by expansion, and those at the top its average pressure at that degree of expansion.

The condensation of steam by radiation of heat from the cylinder, the leakage of the steam through the piston or valves, or the expansion of the steam in the nozzles of the cylinder, the steam-pipes, or the extra length of cylinder allowed for clearance of the piston, will vary the shape and termination of the curve. It should, therefore, always be an in-

quiry, upon the production of a diagram, whether this curve be theoretically correct or not. If it is not, a satisfactory reason should be found for it in the construction of the engine, or the valves and the piston should be thoroughly examined. A ready method to deter-

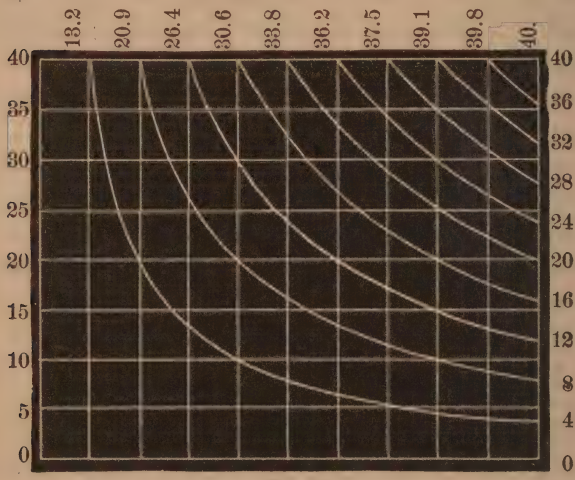


Fig. 39

mine at what point this curve should terminate, is to find the capacity of nozzles, pipe, etc., from the expansion-valve to the cylinder, and, adding it to the clearance, call it so much additional length of stroke. Extend the diagram in the same proportion, and then divide it into any number of parts that will divide it equally, and have one of the divisions cut it

at the point where the valve closed. Take the number of those divisions on the steam line for the numerator of a fraction, and the whole number of them for the denominator, and divide with it the whole pressure upon the piston. Thus, Fig. 39 may be divided in ten equal parts, two of which measure the steam line, and therefore the divisor is the fraction 2 10, the dividend being 54, which, divided by 2-10 =10.8, for the point where the curve ought to have terminated.

Ques. Will you now give me some specimens of indicator diagrams, taken at different times, and under various circumstanes, with such explanations as will enable me to form correct opinions of the performance of such engines as I may have occasion to examine with its aid?

Ans. Were the the steam-engine a perfect machine, working without expansion, and without lead to the valves, and with a perfect vacuum in the condenser, its diagram as shown on an indicator card would be a parallelogram.

Supposing diagram No. 40 to be taken from *such* an engine, having ten feet stroke, working without expansion, and with no lead to the valves, the action of the steam would be as follows: The steam would enter at A, and follow to B, forming the "steam-line;" the exhaust-valve would then open, and the pressure would instantly fall to D, forming the "exhaust-line;"

while the exhaust-valve was open the vacuum line, C–D, would be formed; at C, the end of the double stroke, the exhaust-valve would close and the steam-valve open, causing the steam-pressure to instantly rise to A; cutting off at half-stroke (5 feet), the steam would enter at A, and follow to E, when the valve would close; the steam would then expand from E to F, with a constantly diminishing pressure; at F the exhaust-valve would open, and the line F–D, D–C, and C–A, would be formed as before.

Should the steam line A–E, instead of being a straight line, like A–E, be a slanting one, like A–P, it would show the throttle-valve to be partially closed, the steam-ports too small, or that the boiler could not keep up the steam to its full pressure, as at the beginning of the stroke. If the exhaust line, instead of being the straight line, F–D, was the line H–S, it would show that the exhaust-valve opened *too soon*, when the piston had travelled only 9 feet. But if it showed the line F–K, it would show the exhaust-valve *opened too late*, or that the exhaust ports were too small to give a free exhaust. Should the lead line, instead of being the straight line C–A, show the line M–N, it would show excessive lead, the valve opening when the piston had yet one foot of its stroke to complete; but if the lead line should be C–N, it would show that the valve had no lead at all, but on the

contrary the piston had travelled some distance before the valve opened. To produce a card with well-defined angles (right angles) it is evident that the pressure upon the piston of the engine must be changed from one side to the other *instantaneously*, or nearly so, a usage which few engines would be able to stand ; therefore while economy of fuel demands well-defined angles, the safety of the engine and economy of repairs must direct the engineer how near he can approach to them.

Diagram 35 was taken from a beam engine cutting off at about 3 feet 6 inches, with a stroke of 10 feet. The expansion line fell below that due for that amount of expansion, and was caused by radiation of heat from the cylinder, as it was not protected from such a loss either by a jacket, or covered with felt, and lagged.

Diagram 36, taken some time afterwards, showed, by the expansion line being too high, that the steam-valve leaked, allowing steam to enter the cylinder after the cut-off had dropped into its seat.

Diagram 37 is a diagram from a beam engine cutting off at less than 1-10 the stroke, with Sickles' cut-off, which is a *very good* diagram and about as nearly perfect as it is possible to get them in practice.

Fig. 40, with the accompanying explanation,

will give you an idea of the cause of defects in any and all diagrams, and the alterations to be made in the engine to remedy those defects. Should you take a diagram from your engine, and it should show no lead, turn the eccentric ahead a little until the diagram shows enough. If too much lead, turn the eccentric back until the indicator produces the desired diagram. If the diagram shows leaky valves, grind them in. Knowing the cause of the trouble the remedy can be practically applied.

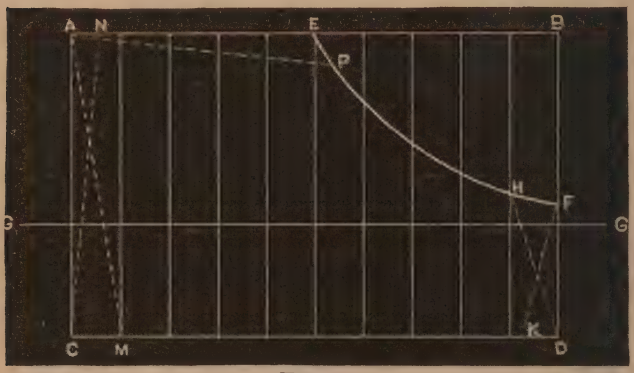


Fig. 40.

INDICATOR DIAGRAMS—HOW TO READ THEM.

A B—Steam line; *E F*—Expansion line; *F D*—Exhaust line; *C D*—Vacuum line; *G S*—Atmospheric line; *A C*—Lead line

TO KEEP THE INDICATOR IN ORDER.

After the indicator has been used, and before putting it up, it should be taken apart

and carefully cleaned and dried, to prevent injury to the springs, and to keep the dust and dirt from scratching the cylinder and piston; and, before using it, the cylinder and piston, and the axis of the paper cylinder, should be lubricated with some clean oil. If, in the use of the indicator, the cylinder or piston should get cut or scratched, so as to interfere with the freedom of its motion, they should be delicately scraped and burnished, or ground with some nicely prepared powder or tripoli.

CHAPTER XXIII.

EXPANSION OF STEAM.

Ques. What is meant by expanding steam, or working steam expansively?

Ans. The force (steam) acting upon the piston of a steam-engine is the excess of the forward-pressure above the back-pressure, exerted by the steam as it comes from the boiler. There are two stages in the action of the steam—the admission and the expansion. During the admission the steam comes from the boiler to the cylinder, and it exerts a pressure somewhat less than that in the boiler, on account of the friction caused by the pipe, throttle-valve, and

steam-ports. The admission is terminated by the cut-off, that is, by the closing of the valve which admits the steam into the cylinder; then follows the expansion of the steam which is confined within the cylinder, as it drives the piston before it, exerting a constantly diminishing pressure. Now, it is clear that work continues to be done, by the steam expanding, and driving the piston so long as the forward-pressure exceeds the back-pressure. Hence, the higher the forward (or boiler) pressure and the lower the back-pressure, the greater is the efficiency of the steam in an engine.

Ques. At what point of the stroke is it best to cut off the steam?

Ans. Theoretically, it would be that point which would cause the steam by its expansion just to exceed the back-pressure at the end of the stroke; but practically, you cut off at such a point as to drive the boat at the given speed, or do the work required. A good rule to go by is, carry all the steam you can prudently; keep your throttle-valve *wide open*, and cut off as close as you can. This is the way to run your boat economically.

CHAPTER XXIV.

CUT-OFFS.

BEAM ENGINES.

Ques. What kind of cut-off valves are mostly used in sidewheel steamers?

Ans. There are three makes of cut-offs in general use, and they all give satisfaction; they are "Stephens'," "Sickles'" and "Winter's." "Stephens'" cut-off makes a showy front, is not liable to get out of order, and cuts off at a given point quite close. The only objection to it is the point of cutting off cannot be altered while the engine is in motion. "Sickles'" has a dash-pot arrangement to prevent the slamming of the valves; it can be altered to cut off at any point without stopping the engine, and it can be adjusted so as to follow full stroke, or not lift the valves at all. As the point of cutting off is changed by merely raising or lowering a small lever, any one can learn how to regulate it in a few minutes. The only thing that requires particular attention is the amount of water in the dash-pots. Should there be too much, the plunger will hang up, and the valve cannot seat; if not enough, the valve will slam. Fill the dash-pot so the valve will seat *quickly*, but without slamming.

There is a small pet cock in the side, to let some water out when there is too much.

"Winter's" cut off has a *revolving* rock-shaft, with cams upon it, by which the lifting-rods with the valves are lifted from and lowered into their seats. This cut-off, like "Sickles'," is momentarily adjustable, and the point of cutting off can be altered while the engine is in motion. From the above description you can easily tell a "Stephens," "Sickles," or "Winters" (the only ones in general use on sidewheel boats), as soon as you see it.

HOW TO SET A STEPHENS CUT-OFF.

Ques. How would you proceed to set a Stephens cut-off, supposing the eccentric loose upon the shaft, and the lifting-toes loose upon the rock-shaft?

Ans. Suppose your engine should have 10 feet stroke, and you wish to cut off at half-stroke, that is at 5 feet. We set the upper steam-valve first. To do this we measure off, on the slides from the top of the stroke, the distance of 2 1-2 feet, and then secure the cross-head just at that point. Next, block up the lifting-rod with the *upper* valve its proper lift (1-4 its diameter), and secure it there by setting up on the binders. Next, secure the pin in the rock-shaft arm, about midway in the slot-hook on the eccentric rod, and then turn the ec-

centric forward its *full throw*, and then turn the toe on the rock-shaft up until it just touches the upper toe on the lifting-rod; secure the eccentric and toe on rock-shaft, and the *upper* valve is set to cut off at half-stroke. To set the *lower* steam-valve, you merely turn the engine back until the eccentric gives its full throw backwards, and then blocking up the lower steam-valve to its proper lift, you turn the other toe on the rock-shaft up until it just touches the toe on the lifting-rod, and secure it, and both your *steam*-valves are set. To set the exhaust-valves you place the engine on the centre, secure the pin in the rock-shaft arm, and also the toes, and then turn the eccentric around until it gives the proper lead, and then secure it.

The *steam*-valves on a beam engine require *no lead*. They should be set so as to just begin to lift as the crank passes the centre; but the *exhaust*-valves should have some lead. Poppet-valves set in this way as regards lead will give satisfaction.

Ques. Will a Stephens cut-off cut the steam off equally from both ends?

Ans. No, it will not. The best practice is to set it so as to follow further on the lower side, as the steam has the weight of the piston, cross-head, links, etc., to lift on the upstroke.

Ques. What precaution must be taken in setting this cut-off ?

Ans. The pin in the rock-shaft arm must not be raised so high that the eccentric will *throw in a straight line;* if it does a breakdown will be the result. By lowering the toes on the rock-shaft, it cuts off *shorter;* by raising them it cuts off longer. After altering the toes to give a different cut-off, the pin in the rock-shaft arm must be raised to preserve the lift of the valve, and also move the eccentric forward so as to lift the valve at the proper time.

CHAPTER XXV.

CUT-OFFS.

SCREW ENGINES.

Ques. What kind of valves are used as cut-off valves in screw engines?

Ans. In some engines the steam is cut off or expanded to a limited extent by means of *lap* upon the valve; in others, by using the "link motion," which reduces the travel of the valve, and *squeezes* the steam off; while in most cases an independent cut-off valve is used, which consists of two movable plates set upon the back of an ordinary three-ported slide-valve and

which plates are pushed apart or down together by a right and left handed screw passing through both plates, and which is regulated by turning a wheel on the top of the steam chest. To cut-off shorter, you merely turn the wheel and push the plates apart ; to follow further you draw them closer together. This is a most excellent arrangement for cut-off valves for screw engines, and for it the engineering world is indebted to that eminent English engineer, John Bourne, who patented it and brought it out in the year 1838.

CHAPTER XXVI.

HOW TO SET A SLIDE-VALVE.

Ques. What is the mode of setting slide-valves ?

Ans. Place the engine on the centre (as directed elsewhere); when the crank is thus placed on the centre, the valve is fixed so as to have the amount of lead intended, and then the eccentric is turned around on the shaft, until the hook in the eccentric-rod falls into gear with the pin on the rock-shaft; the eccentric is then secured in place by set screws or keys.

Ques. How is the valve set when the "link motion" is used ?

Ans. The same as above, first setting the valve to the go-ahead eccentric, and afterwards to the backing eccentric. In setting a valve with either the link motion or single eccentric, the first thing to do is to find if the eccentric-rod is of the proper length; and this is done by turning around the eccentric, and marking each extremity of the travel of the end of the rod. The valve attachment should be between these extremes, and if it is not so, it must be made so by lengthening or shortening the rod. When the rod is of the proper length proceed as above directed. It may be set down as a general rule that all valves—slide, poppet, or any other make—if they be worked by an eccentric, are set in the same way, as the crank must stand in the same place (on the centre) when the valve has just opened to admit steam without regard to kind or construction of engine or valves.

The *best* way of all to set *any* kind of valve is to use an indicator. It tells just when the valve or valves open and close; whether they open too soon or too late; whether there is too much or not enough lead to both the steam and exhaust-valves. It also tells if they leak, or if the steam-ports are too small; in fact everything connected with the working of the valves.

CHAPTER XXVII.

MARKING ENGINES.

Ques. What advice would you give to an engineer on taking charge of a new or strange engine?

Ans. He should mark with a scriber, or cold chisel, the different working parts, so he can easily replace them, should they slip. Thus should he mark the eccentric and shaft at the same time, and if the eccentric should afterward slip he can easily reset it by merely bringing the chisel-mark on the eccentric in contact with the mark on the shaft. In beam engines, when the upper toes are fixed to the lifting-rods by set-screws, the lifting-rods should be marked so that should the toes slip they can be easily reset. All keys should be marked, and then you can tell at a glance if they are working loose. Set-screws are a very unreliable means to secure eccentrics or other parts together, and they should never be used when they can be secured by a key. Just fancy an eccentric slipping when the steamer is running in a crowded river at night, or rolling in the trough of a heavy sea, and you will realize the necessity of having the different parts marked so that you can instantly replace them.

CHAPTER XXVIII.

HORSE-POWER OF AN ENGINE.

Ques. What is meant by the horse-power of an engine?

Ans. A horse-power is equal to lifting 33,000 pounds one foot high in one minute.

Ques. How is the horse-power of an engine determined?

Ans. Find the number of square inches in the cylinder, then multiply that by the pressure of steam plus the pressure due to the vacuum, and then multiply this sum by the number of feet the piston travels per minute, and divide by 33,000; the result is the horse-power.

Ques. How do we find the number of square inches in the cylinder or piston?

Ans. Square the diameter, and multiply by the decimal .7854.

Ques. Will you give an example?

Ans. Suppose your engine is 40 inches in diameter, and 10 feet stroke, and makes 20 revotions per minute. Pressure of steam per gauge, 30 pounds per square inch. Vacuum, 26 *inches*—not pounds. As 30 inches of vacuum is equal, in round numbers, to 15 pounds pressure, every

two inches of vacuum equal one pound pressure.

Now, we square the diameter 40
by multiplying it by 40
1600
And that by the decimal .7854
6400
8000
12800
11200
1256.6400 which is the number of square inches in the piston.

Now, leaving out the fraction .6400, we take the whole number 1256 (which is near enough for practical purposes), and multiply it by the pressure, which is:

Steam 30
Vacuum 13
43 = total pressure.
1256 = square inches.
43 = pressure.
3768
5024
54008
And that by 400 = speed of piston in feet per minute.
33.000)21603200(654$\frac{21200}{33000}$ Horse-power.
198000
180320
165000
153200 20 revolutions.
132000 20 feet per revolution.
21200 400 feet per minute.

which gives 654 and a fraction horse-power. In this example the steam follows full stroke, and the engine exerts its greatest power. When the steam is cut off, the *mean* pressure must be taken; but it is always best to calculate with

full stroke, and thereby find the greatest power the engine is capable of exerting.

CHAPTER XXIX.

TO PUT AN ENGINE ON THE CENTRE.

Ques. How is an engine put on the true centre?

Ans. To put it on the top centre, we place the cross-head within a few inches of the top of its travel, and then make a mark on the slide by drawing a scriber or knife blade across it, laying the scriber on the gibs. We then go back to the "thrust-bearing," and with a cold chisel nick the shaft and cap of pillow-block at the same time. We then turn the engine around until the gib comes up to the mark on the slide again; then going back to the thrust-bearing, we nick the shaft again, to correspond with the nick in the cap of the pillow-block. With a pair of dividers we get half the distance between the two marks on the shaft, and this point or mark brought back to nick in the cap places the engine on the true top centre. The engine is placed on the bottom centre by similar means, marking the slides near the bottom. You can use the balance wheel in-

stead of the thrust-bearing for marking if more convenient.

Ques. Is a sidewheel engine placed on the centres by similar means?

Ans. It is. You mark the slides as before, and nick the shaft at the spring-bearing, or in fact any stationary part with which the shaft comes in contact.

CHAPTER XXX.

THUMPING OF ENGINES.

Ques. What causes engines to thump, especially when the engine is passing the centres?

Ans. The causes are many and various. It may thump because the shaft, cross-head, or slides are out of line; the crank-pin, shaft, or couplings may be loose; there may be and often is a collar formed in the cylinder by long wear, against which the piston brings up as it passes the centres, in which case the collar must be chipped or filed off. Some of the keys of the stub or fork-end of the connecting-rod may be loose; the piston packing may be loose, and need setting out; or the valve and its gear may be out of order. On hearing a

heavy and unusual thump or noise about your engine, first examine all the keys and caps, to see if they are tight; if they are all right, take off the cylinder-head and see if a collar has formed in the cylinder; if not, examine the piston packing, and set it out if necessary. Try the piston itself; it may be working loose on the rod. If the air-pump is worked by the main engine, examine its piston; perhaps it will be found loose; next examine the main-valve, and see if it has the usual lead; also, the eccentric and link motion. Having done this, and all having been found in order, if the thumping still continues, you may take it for granted that the shaft, slides, or cross-head is out of line, and you must line it up as directed below.

CHAPTER XXXI.

LINING UP AN ENGINE.

Ques. How would you proceed to line up an engine?

Ans. Sometimes when the engine thumps, or otherwise works badly, it is advisable to try its different parts to see if they are in line. To do this, assuming that the cylinder is in its proper place, we run a line through the centre of the

cylinder, measuring from different points to get the line exactly in the center, and make it fast in the crank-pit; then—

TO LINE UP THE SLIDES.

Measure with a straight-edge the distance of the slides from the line at the top and the bottom, and if the measurements are not the same, liners must be used to set them true.

TO LINE UP THE CROSS-HEAD.

If the connecting rod has a fork-end, and there is a hole in the cross-head for the piston-rod, if the line does not pass through the centre of the hole, the cross-head is not true, and the gibs must be adjusted to make it so.

TO LINE UP THE SHAFT.

To line up the shaft, bring the crank around nearly on the top centre, just so that it will touch the string, measure the distance of the forward end of the crank from the line, then turn the crank around on the bottom centre as before, and measure the distance of the crank again. If all the measurements are the same, the shaft is in line, that is, it stands at right angles to the centre of cylinder; but if the measurements are not the same, the shaft is out of line, and it must be raised or lowered until the measurements are the same. Example. Suppose the crank-pin be 5 inches long, and (taking an ex-

treme case) the distance of the string is 3 inches from the forward crank, and 2 inches from the after one when on the top centre, and the reverse when on the bottom, it shows the forward end of the shaft is down, and needs raising 1-2 inch. Of course, the example is an extreme case, and in practice the measurements will seldom differ more than 1-8 inch. This method saves the trouble of taking out the crank-shaft, which would have to be done to use a T-square for the same purpose. A plumb line cannot be used on board ship, and straight-edges and T-squares are used instead.

Ques. How is the shaft of a sidewheel steamer lined up?

Ans. Put the crank in the top and bottom centre, and measure the distance between the cranks; if the distance is greater when on the top than when on the bottom centre (as it will probably be), it shows that the outboard end of the shaft (one or both) is down, and it or they must be raised until the measurements are the same. To see if they are in line fore and aft, put the crank on the fore and aft half-centres and measure as before; if the measurements are not the same the shaft (one or both) must be moved forwards or backwards until the distances between the cranks are the same.

CHAPTER XXXII.

LINERS.

Ques. As all brasses wear more or less, what is to be done when the wear is considerable?

Ans. When the brasses have worn until they are "brass to brass," that is when much worn and have been keyed up until they touch, they must be taken out and filed off until they do not touch by 1-8 of an inch. The amount taken off is then made good by placing "liners" (thin pieces of copper, sheet-brass, tin or sheet-iron) between the brasses and rod-strap or cap. The English practice is to bind all brasses "brass to brass," filing them down as they wear, which is the better plan. Care must be taken in using liners, when the clearance is small, not to lengthen or shorten the connecting-rod so as to cause it to strike the top or bottom of the cylinder. After overhauling an engine in any way, it is always advisable to turn it over *by hand*, to be sure that all is clear before getting steam. Screw engines can be turned with a pinch or pry bar, and sidewheel engines with the wheels.

Ques. What is meant by clearance?

Ans. Clearance is the distance of the piston from the top or bottom of the cylinder, when

the engine is on the true centre. Most engines have about 3-4 inch clearance, and the liners should be used so as to keep it at that. The object in using liners is to keep the rods, etc., at their proper length.

CHAPTER XXXIII.

ON COMING INTO PORT.

Ques. Previous to coming to anchor, or making fast to a wharf, ought not the engineer to be informed of it?

Ans. He should be so informed at least half an hour beforehand, so that the fires may be permitted to burn low, by which means coal will be saved, and there will only be a light fire to haul or bank; besides, the great nuisance of blowing off at the safety-valve will be obviated.

HAULING FIRE.

Ques. If the vessel will be in port several days should not the fires be hauled?

Ans. The fires should be hauled, and the water blown out of the boiler; the manhole and handhole plates should then be taken off, and the boiler washed out with the hose attached to the deck-pump. The water should

not be blown out so soon as the fires are hauled, but the boiler should be allowed to cool off somewhat, otherwise the sudden contraction of the metal will cause the seams or patches to leak.

After the water is blown out of the boiler there is more or less remaining in the legs, and always below the handholes; if you wish to get clear of this for making repairs, which is sometimes necessary in this part of the boiler, for the purpose of putting a bolt through from the inside to be set up with a nut from the outside, you would find it very difficult to do, especially in cold weather, if there was water in the legs. To remove this, make a syphon—a piece of small hose 2 feet long will do; fill this with water, keeping the ends together; insert one end in the handhole, and let go the other instantly, and the water in the legs will follow.

Ques. Supposing the fires hauled, and the water blown out, what then?

Ans. Sweep the tubes, clean out the front and back connections, the flues, and the furnaces of all ashes and dirt. The ash-pans should be hauled, picking out any good coal which may be among the ashes, and the ashes be thrown overboard if possible. After the boiler is cleaned up and washed out, any needed repairs should be made. Every engineer in charge of an engine should keep a note-book, making a note every

day of any faults in the engine or boiler. For if he trusts to his memory alone, something very important may be forgotten.

SCALING BOILERS.

Ques. In what manner is the scaling of boilers performed?

Ans. The scale is chipped off with sharp-faced hammers called scaling-hammers, and those parts which cannot be reached with the hammers, with long flat-faced bars called scaling-bars. After the scaling has been performed, the boiler should be thoroughly washed out, and all the scale, mud, etc., taken out of the lower handholes.

Ques. Are not certain chemical compounds used for removing scale?

Ans. It is said that all such compounds injure the iron while removing the scale, and therefore the better plan is to use hammers, as before directed.

SWEEPING TUBES.

Ques. How are the tubes swept?

Ans. With brushes made for the purpose, fixed to long iron rods. Some engineers blow them clean with steam, using a piece of steam hose with a nozzle just fitting the tube. This is a quick way of doing it, and it can be done with steam in the boiler. Sweeping tubes is a

most disagreeable and dirty job. Nevertheless, they must be swept at least once a week, or they will become choked up with dirt and ashes, kill the draught, and cause the boiler to steam badly. The large flues leading from the furnace to the back connection are swept with large flue-brushes fastened to a line, by two men, one at each end, pulling it backwards and forwards.

Ques. What precautions should the engineer take after the vessel is at anchor, or made fast to the wharf, to prevent fire, leaks, etc.?

Ans. After the work of the engineer is done for the day, let him not be in too great a hurry to go home, or ashore, as the case may be. But let him first look round and see if everything is all right. See that there is no fire in the engine room. If there is a lamp left burning, or a lighted pipe, or matches are lying round loose, they may be the cause of destroying the vessel. There have been such cases. See that the throttle-valve is closed tight, to keep the steam that may be in the boiler (after the fires are banked) from going into the cylinder and condensing, thereby causing a great deal of water to be worked off by the engine. If there be a stop-valve on the boiler, close it also.

This also applies to the fireman. He must see that the furnace door is hooked back, and that the connection doors are open, and the damper (if there be one) is closed, leaving only a crack for

the escape of the gas and smoke. Also, look to the sea cocks, see if they are closed or shut off. If they be left open, some of the pipes might burst or split, and sink the vessel at the dock.

CHAPTER XXXIV.

OVERHAULING THE ENGINE.

IN PORT.

Ques. What should be done to the engine while the vessel is in port?

Ans. The piston packing should be examined, to see that it is neither too tight nor too loose, also the slide-valves, to see if they are smooth and tight, and have the proper lead. The stuffing-boxes should be repacked if necessary. The air-pump and its valves should be examined, and new valves put in if the old ones are much worn.

Try the surface-condenser to see if the tubes leak, which can be done by filling it with water on the steam side. Examine brasses and journals. Should they be cut, draw-file the journals, and scrape the brasses to a true smooth surface. The engineer can tell by the way his engine works at sea about what is to be done when in port. If you have plenty of

time, try your cylinder with a pair of inside-calipers to see if it be true; perhaps you will find it wearing oval, or wearing more in the centre than at the top and bottom, or *vice versa;* then adjust your piston packing accordingly.

Try the slides, cross-head, and crank, to see if they are in line.

If the cylinder is scratched or cut, use pulverized plumbago (black lead) mixed in your oil in proportion of 1-2 pound to the gallon; it will both stop the cutting and put a beautiful polish on the cylinder and piston-rod. Dixon's plumbago, which is sold by all dealers in engineers' stores is a most excellent article, pure and free from grit. While in port the engineer should also lay in his stores, oils, waste, soap, packing, etc., for the next trip. All these things require his personal supervision, and they should not be entrusted to the fireman or others. A chief-engineer of a ship is not supposed to work, but he *is* supposed to furnish *brains* for those who do; he should superintend *all* repairs himself, to see that the work is well done, and not trust too much to the machinist or boiler-maker, many of whom are anything but skilled mechanics, and who will bear watching.

I wish to say in conclusion on this subject, that in steam engineering, as in everything else, it is a good thing to "let well enough alone."

If your engine really needs repairing, repair it, but don't be forever tinkering at it, for, rest assured, the more you tinker at it the worse it will get. I once saw a new beam engine badly used up, the engineer tinkering at it every day in his vain endeavor to remedy some trifling defect which no experienced man would have noticed.

CHAPTER XXXV.

GRINDING-IN OF VALVES, COCKS, ETC.

Ques. How are valves, cocks, etc., made steam and water-tight?

Ans. By grinding them in with ground glass, or flour emery, the glass being mostly used when grinding-in a plug-cock if it is badly cut or scratched. A great deal of labor may be saved by first draw-filing it to a fair surface, and then grinding it to a tight fit; mix your glass with oil, and apply only a little at a time. It requires both time and patience to make a good job. Plug-cocks are only used on account of their cheapness, and are every way inferior to globe-valves.

Ques. Is it not a difficult matter to grind in poppet-valves tight?

Ans. It is rather, because though tight when cold, they will leak when hot, owing to the

valve and seat not expanding alike. Every new valve leaks, after having been in use but a short time, and as a rule, they are a constant source of trouble and expense.

Ques. How are slide-valves made steam-tight?

Ans. By scraping them to a true surface with a scraper, according to the indications of a straight-edge. The valve and face should be trued up separately, and then scraped to each other, in the following manner: Take a little red lead, thinned with oil, and smear it over the valve-face with your finger, wiping it nearly dry; then place the valve in its seat and slide it backwards and forwards, just as the eccentric does; wherever the lead shows in spots or patches, must be scraped. Continue this operation until the lead shows the same all over the valve and seat.

Ques. What kind of a scraper should be used?

Ans. A worn out half-round file, ground down (on the grindstone) to a sharp edge will answer, if one made for the purpose is not come-at-able.

Ques. Should not all brasses be scraped true to their journals?

Ans. Yes, and if they were, there would be fewer hot journals, and less talk about an "engine wearing down to its bearings," and, if all

planed surfaces were scraped, less sheet-gum would be in demand.

CHAPTER XXXVI.

PACKING.

Ques. What kind of packing is generally used for packing stuffing-boxes?

Ans. There are several most excellent makes of packing, any one of which will give satisfaction. I recommend the following brands in the order in which they are named, viz., "Empire," "Asbestos," "Tucks' improved," "Soapstone," and "Eagle." There are also several makes of metalic packing, which are highly recommended.

Ques. What is the proper way to put packing into the boxes?

Ans. Cut the packing in lengths equal to the circumference of the rod, less about 1-4 of an inch. Fill the box, breaking the joint with every piece, and screw the gland up tight; then work the engine a little while, and when the packing has become warmed, slack up the gland until the nuts are only finger-tight; the packing then will expand and become steam-tight. You must be careful in setting up the gland to

see that it does not touch the rod, but sets up evenly all around.

OILS, ETC.

Ques. What kind of oil is best for lubricating machinery?

Ans. Lard oil; and I recommend its use for the cylinder and valves, as well as for the journals. Many engineers use "cylinder oil" and tallow in their cylinders, but my experience is, that good lard oil is all that an engineer needs for any purpose about his engine.

Ques. How often should an engine be oiled?

Ans. That depends upon circumstances. Some engines require oiling up every half-hour, others every hour, and so on. So long as the brasses keep cool they will not cut. The proper way is to have a set time for oiling, and then go round with a squirt-can and squirt a little in each oil-hole; the crank-pin will require more than any other. The cylinder ought also to be supplied at regular intervals, and not neglected until it "grunts for grease," as it will do when it becomes dry.

Ques. Is not a great deal of oil sometimes wasted?

Ans. There is no sense or reason in slushing an engine with oil, and a bearing which a moderate supply will not keep cool, will be found to be keyed-up or screwed down too tight, out of line, or deficient in bearing surface.

Ques. What is the proper way to key-up or screw down a journal?

Ans. If a key, drive it well home, and then back it out a little, say 1-16 of an inch, or so, or if a screw and nut, jam the nut tight, and then turn it back a half turn or more. Of course, you must use some judgment, as I cannot give you an exact rule in all cases. Should the journal be disposed to heat, slack up more, but not so much as to cause a thump. With a little practice you will be able to do this to a nicety.

Ques. Should not all the brasses be taken off and examined occasionally?

Ans. Yes; and care should be taken that the oil-hole does not become gummed up, or choked with dirt, grit, etc. When in port, it is a good idea to keep all the oil-holes plugged with clean cotton-waste, to protect them from the fine ashes, etc., which are generally flying round an engine-room when repairing and cleaning-up are going on.

Ques. Will not the piston-rod and valve-rods, when rough and scratched, cut the packing and cause it to leak?

Ans. They will, and the remedy in such cases is to draw-file the rod to a smooth surface and afterwards polish it with a piece of fine emery cloth rubbing it in the direction of its length.

Ques. What cuts and scratches the rods?

Ans. Dirty and gritty packing, and for this reason, packing should always be kept in a clean box, or locker, free from all dirt, grease, etc.

Ques. Should not all piston-rods, valve-rods, etc., be of steel instead of wrought-iron?

Ans. Yes, and it is generally used now for such purposes.

Ques. What kind of packing is used in steam-pistons?

Ans. Cast-iron rings set out by steel springs; but brass rings, made of copper 15 parts, and tin 5 parts, make an excellent packing, which requires very little oil. Another advantage is, the wear is on the rings and not on the cylinder, and it is much cheaper to buy new rings than it is to bore the cylinder out. In setting out piston-packing, care must be taken to have it neither too tight nor too loose, because if too tight the friction will be great, requiring considerable power to move it, and probably cutting the cylinder; on the contrary, if too loose the steam will blow through, causing a loss of steam and power.

Ques. You said piston-packing is set out with steel springs?

Ans. Well, yes, they call them springs, but there is very little "spring" about them. Indeed, the most of them are as rigid as a screw-jack when set out. There is a fortune in store

for the man who will get up a real *springy* spring for that purpose.

Ques. How can one tell when the piston is tight?

Ans. By taking off the cylinder head and giving steam on the opposite side. When, if it is not tight, steam will blow through.

Ques. What precaution should be observed in setting out piston-packing?

Ans. It should be set out equally all round, so that the centre of the piston will stand in the centre of the cylinder.

Ques. How can we tell when the centre of the piston is in the centre of the cylinder?

Ans. Place one leg of a pair of dividers in the centre of the piston, and the other leg where the rings touch the cylinder, and describe a circle; or use a pair of inside-calipers, measuring from some part of the spider.

Ques. What is the spider?

Ans. It is the body of the piston itself, minus the rings and follower.

Ques. Should not the rings be scraped to each other, and also to the follower?

Ans. They should, and the follower should be bolted down with *iron* bolts, working in brass nuts.

Ques. Are not stuffing-boxes and glands made of cast-iron?

Ans. They are; and they should be bushed

with composition, which will prevent the rods from being cut should they chafe.

Ques. What kind of packing is used in the pistons of air-pumps and other water pumps?

Ans. Hemp-packing, plaited and soaked in tallow, and it answers very well for such purposes.

Ques. What tools are used in putting new packing in, or taking old packing out?

Ans. Almost anything made of *wood* will answer to push new packing in with, but to take old packing out you need a packing-hook and a worm; the latter is nothing more or less than a cork-screw with a long handle. A gun-screw, such as is used to draw charges, fixed to a ramrod, is a good substitute.

CHAPTER XXXVII.

STARTING FIRES.

Ques. What is the proper way to start a fire?

Ans. Before proceeding to start the fire, you must see that the man and handhole plates are put on (if they have been taken off for cleaning out or repairs), and the joints properly made. If the boiler is new, or in

good order, a gum-gasket is all that is required to make them tight, but if the boiler is old and worn about the handholes, it will be necessary to put two or three turns of lamp-wick around the gasket, smearing it with white lead. After the plates are all on, fill your boiler with water until the glass gauge is half full, then cover your grate-bars all over with coal, and put in two or three layers of cordwood (pine is the best). Then take some shavings, split-wood, or oily waste, place it over and about the wood next to the door, and light it, keeping the furnace-door *open* and the ash-pan door *shut* (if there be one) until the wood is thoroughly ignited, and then, and not until then, shut the furnace-door (and open the ash-pan door if there be one) and cover the wood with coal, adding to it as fast as the wood burns away; in a short time you will have a splendid fire. Steam can be raised a half-hour sooner in this way than by the common method of putting the wood on the bare grate-bars.

Ques. Must not the safety-valve be kept open while raising steam?

Ans. Yes, to let the air out, and be closed as steam shows itself at the escape pipe, that is the safety-valve pipe; when the steam-gauge shows 4 or 5 pounds, open the stop-valve on the boiler, and the pet-cocks or "bleeders" in the steam-pipe and steam chest, to free them of

water; then open the throttle-valve and warm the engine up.

GETTING UNDER WEIGH.

Ques. What should be done previous to getting under weigh?

Ans. Previous to getting under weigh, and before reporting "ready," if the steam is up to the required pressure, open the water-cocks on the cylinder and work the piston up and down several times, to work the water out; then turn it over slowly a few times (giving some injection water to form a vacuum), to see that everything is all right. Fill the oil-cups, also tallow-cups on cylinder, and you are ready to start. If the vessel is a side-wheel steamer, it is advisable always before starting, to look into the paddle-boxes to see that everything is clear; great damage may be done by neglecting this precaution.

ENGINEER'S DUTIES WHILE ON WATCH.

Ques. What are an engineer's duties while on watch.

Ans. The engineer on watch should give his whole attention to his duties while the engine is in motion, as any neglect or carelessness on his part may be attended with disastrous results. He must see that the steam is carried at a uniform pressure, or nearly so; that the water

in the boiler is carried at its proper level, and at its proper density; the fires kept clean, and evenly spread on the grates; that the journals are oiled at regular times, and not permitted to get hot and to cut. He should closely watch all the working parts, to see that none of the keys, nuts, etc., are working loose; in a word, he must be constantly on the alert, with both his eyes and ears open. Sometimes the mere dropping out of a single key, or the unscrewing of a single nut may cause a breakdown which cannot be repaired at sea. A great many engineers, after having had charge of an engine for a long time, and getting used to it, become somewhat careless, and this is how some of them get caught napping. An engineer should remember that eternal vigilance is the price of *safety*, as well as liberty.

CHAPTER XXXVIII.

FIRING.

Ques. How thick should the fire be kept on the grate?

Ans. It depends altogether on the draught. If the draught is strong, it should be heavier than when it is weak, and a bituminous (soft) coal

fire should be thicker than one of anthracite (hard) coal. But whatever the thickness, it should be kept spread evenly all over the grate, and not allowed to burn in holes, leaving the bars bare, as the cold air will rush in and chill the heating surface. A soft coal fire needs breaking up at short intervals, as it has a tendency to amalgamate, or crust over on top, but a hard coal fire should not be broken up with the bar. All that is necessary to clean it of ashes is to run the slice bar over the grate and withdraw it without breaking up the body of the fire. The clinkers should be taken out with the "devil's-claw." Whatever is done to a fire should be done quickly, and the furnace door be kept open no longer than necessary. No two fires should be cleaned at the same time. While the cleaning is going on the throttle-valve should be closed a little, or the steam cut off shorter, until the new fire begins to make steam again.

Ques. What is the proper way to clean a fire?

Ans. Take a hoe and push the upper part of the fire back, leaving the clinkers, ashes, etc., on the grate, then pull the ashes, etc., out with the hoe. To clean the back end of the grate, you pull the good fire forward again, and draw the clinkers and ashes of the back end *over* the fire, and into the ash-pan. Having

cleaned it, you must spread the fire evenly all over the grate, and then cover it over with fresh coal, but not too heavily. Care must be taken with anthracite coal, not to let the fire burn too low before cleaning it, or else you will not have fire enough left to cover the grate, and it will die out.

Ques. What is the proper way to bank a fire?

Ans. Clean it as before directed, and then push it back, leaving the front half of the grate bare, and afterwards cover it over heavily with fresh coal.

Ques. Which do you consider the better coal for steam purposes, anthracite or bituminous?

Ans. Some boilers are better adapted for burning hard coal than for burning soft, but which ever kind you use, get the best, clean, fresh-mined, and free from slate, etc. It is cheaper in the end to get a good article, even when you have to pay more for it. It "don't pay" to buy refuse coal and dirt at any price, and besides, the labor is hard enough with the best of coal. There is more heating power in one ton of good coal than there is in ten tons of coal-dirt, and therefore it is false economy to buy the latter.

Ques. How can one select a good article of coal?

Ans. All fresh-mined coal has a black, bright look, while coal which has been mined a long time, or been exposed to the weather, has a kind of sun-burnt look about it, which almost anybody will notice. Coal should be kept under cover, and not exposed to the weather. I will say in conclusion on this subject, that with good coal, and a good fireman to handle it, the cost of fuel will be reduced to a minimum.

Ques. What constitutes a set of fire tools?

Ans. A shovel, a long-handled heavy hoe for cleaning the fire, a light short-handled hoe, a devil's-claw, a heavy slice-bar, and a light T-bar (a T-bar is a light slice-bar with a point shaped like the letter T) and pricker, and a coal-maul, for breaking large lumps of coal.

CHAPTER XXXIX.

FOAMING.

Ques. What is meant by foaming?

Ans. Foaming, or as it is sometimes called priming, is a violent ebullition of the water in the boiler.

Ques. What causes foaming?

Ans. The great cause of foaming is too little water-space and steam-room in the boiler, de-

fective circulation of the water, owing to faulty design; or the boilers may be too small to furnish the required steam, the engine using it faster than it is formed, thereby taking off the pressure and causing the water to rise to an abnormal height; muddy water will cause it, and also running from salt into fresh water, and *vice versa.* But a boiler large enough to do the work required, of good design, with plenty of water and steam-space and good circulation, will seldom if ever foam.

Ques. How can the engineer tell when the boiler is foaming?

Ans. By the violent agitation of the water in the glass gauge, and by the cracking noise heard in the cylinder. If he try his gauge-cocks while foaming is going on, they will blow forth a mixture of steam and water, instead of *solid* water.

Ques. Is there not danger from the boiler foaming?

Ans. There is great danger, the water being incompressible it may be carried over in the steam in such quantities as to fill the clearance space in the cylinder, and cause the cylinder-head or bottom to be knocked out, and it destroys the vacuum. And again, when the boiler is foaming, and the glass gauge is apparently full of water, if you stop the engine the water will fall to its true level, and may drop

out of the glass-gauge altogether. Here we have another fruitful cause of boiler explosions. When a boiler foams, the level of the water can be found by shutting off the steam, or stopping the engine.

Ques. When the boiler foams what should the engineer do to check it?

Ans. The first thing to do is to partially close the throttle-valve, and slow the engine down, and if there be a cracking noise heard in the cylinder (which is caused by the steam carrying the water in with it), open the water-cocks on the cylinder until the noise ceases. Look at the glass gauge and see how the water stands, and if the foaming be caused by too much water, blow some out. Sometimes when there is a heavy fire in the furnace, foaming may be checked by opening the furnace-door, or closing the damper, if there be one. Not only is there danger when the boiler foams, but the steam and water carry over sand, grit, and other impurities into the cylinder, which cut the cylinder face, and piston-rings, valves and valve faces, and play havoc with the air-pump and condenser.

Boilers which foam badly, or are addicted to foaming, are unfit for use, and the law should strictly prohibit the use of such dangerous rattletraps.

CHAPTER XL.

REPAIRS AT SEA.

ENGINE.

Ques. Are not engineers often required to make repairs at sea?

Ans. Repairs which could be easily made at the shop, where all kinds of tools and materials are at hand, often put the engineer to his wits' end at sea, where only a few tools and the odds and ends of material are come-at-able.

Breakdowns at sea are what bring the man of "mechanical ideas" to the front, and prove him to be the right man in the right place.

Ques. Are not some breakdowns irreparable?

Ans. If a screw steamer loses her screw, breaks her shaft, or if the crank-pin or crank itself breaks, and the piston smashes the cylinder, nothing can be done, and the vessel must make port under sail.

Ques. Suppose a sidewheel steamer should break her shaft?

Ans. In that case the wheel on the broken side should be secured in place, and the ship brought to port with one wheel.

Ques. If the feed-pump be broken in an irreparable manner?

Ans. Feed with the donkey-pump, drawing

warm water from *hot well*, or with the injector, if there be one.

Ques. If the air-pump should break down and could not be repaired?

Ans. Then you must work the engine high-pressure, exhausting overboard, and feed from the sea. Where there is a pair of engines, and one is disabled, disconnect it and drive the ship with the other.

Ques. Suppose the smoke-stack should be carried away?

Ans. In that case you must make a temporary one out of such material as you have at hand. If there be bricks and cement on board build one with them, or stanchions should be put up and chain wove around them.

Every ocean steamer should carry a short piece of extra pipe, in sheets, ready to be put together. Should there be a steam jet in the stack a short piece will answer.

Ques. Should the eccentric rods, or other rods break, or the eccentric itself?

Ans. Put them together with clamps, bolts, or nuts, or the rods can be taken down and forged together, care being taken not to alter their length. No specific rules can be given for all accidents, and the engineer must use his judgment as to what is best to be done. A rule which would apply in one case might not work in another.

Ques. Suppose the feed-pipe should burst, how can it be temporarily repaired?

Ans. Should the feed or any other *water*-pipe burst, mix a stiff putty out of red and white lead, and lay it over the crack in a thick layer; then take some strips of canvas, and bind them round the pipe tightly, overlapping both ends of the fracture, and finish by wrapping the canvas with marline.

To stop a leak in the steam-pipe, cover the crack or hole with a piece of sheet-gum, placing a strip of sheet-brass or copper over it, and wrap with copper wire, drawn tight and close. This is only to be done when you have not the time or means to braze it. All damaged pipes should be taken out and repaired as soon as the steamer gets into port.

CHAPTER XLI.

MODERN MARINE ENGINES—SIMPLE AND COMPOUND.

AMERICAN AND ENGLISH.

Ques. Will you give examples of some modern marine engines, both simple and compound, combining all the latest improvements?

Ans. I will, and shall select as the first ex-

ample, the engine, boiler, etc., for U. S. S. *Manzanitta*, designed by that eminent American engineer, Chas. W. Copeland, of New York, and constructed by the "Vulcan Iron Works," Baltimore, Md. The specifications are as follows :—

CYLINDER.

Cylinder to be 34 inches diameter, and for a stroke of piston of 36 inches; steam openings to be not less than 3 inches wide, and 21 inches long; exhaust opening 4 1-2 inches wide and 21 inches in length; cylinder to be accurately bored and flanges faced.

Bottom head of cylinder to be cast with the cylinder, and well ribbed. All necessary flanges, lugs, nozzles, etc., to be cast on cylinder for the various connections and attachments.

Lower head of cylinder fitted with a small bonnet, with stuffing-box and gland, both bushed with composition; also a composition waste or drain valve 1 1-4 inches diameter, arranged so as to be self-acting or worked by hand.

Cylinder and-steam chest to be felted and handsomely cased with black-walnut staving fastened with brass bands and screws.

The necessary valves and pipes for applying the indicator to be furnished and fitted complete.

FRAMING.

The frame for carrying the cylinder to be composed of the surface-condenser on one side, (with short frame and exhaust-pipe connecting to cylinder), and a cast-iron frame on opposite side from cylinder to bed-plate, or it may be composed of two cast-iron frames, one leg of which to rest upon and be firmly fastened to condenser, and the other leg to extend to and be firmly fastened to bed-plate.

The cylinder to be fastened to condenser and frames by heavy flanges, well bracketed, faced, and strongly bolted; the bottom flanges of condenser and frames to be faced and strongly bolted to bed-plate. All necessary flanges, brackets, nozzles, pillow-blocks, lugs, etc., for all fastenings and connections to be cast on condenser and frames.

STEAM-CHEST.

Steam-chest of cast-iron, well bolted or cast to cylinder; all joint faces to be planed; cover planed and finished, and fastened with finished bolts and nuts. Set screws to be fitted in cover to start it off the joint.

Within the steam-chest is to be properly fitted a false face for the cut-off valve; this face to be so fitted and fastened that it can be readily removed in case of necessity for access to the main valve.

All necessary nozzles for steam-pipes and valves to be cast on chest, and flanges planed; steam-chest to be fitted with a suitable tallow cup.

PASS-OVER VALVE.

In this cut-off face (or on one side of chest) is to be fitted a screw-valve for a by-pass valve 3 1-2 inches diameter; valve and seat and stem of composition; this valve to be worked by a hand-wheel in front of the chest.

RELIEF-VALVE.

There is to be a composition relief-valve 1 1-4 inches diameter, properly fitted and attached to steam-chest, and to exhaust connection to condenser.

SLIDE-VALVES.

The main slide-valve to be of cast-iron, of as different texture from the iron of the seats as possible, and scraped to a tight bearing surface, and of the ordinary D form; for steam openings 3 inches by 21 inches, and exhaust opening 4 1-2 inches by 21 inches, and to be worked by a "Stephenson" link-motion; the link to be case-hardened, and link-blocks of composition; proper hand-gear to be arranged for working the links.

CUT-OFF VALVES.

To be of cast-iron—a "gridiron" valve with two openings 1 1-2 inches by 21 inches long; the

valve to be worked by a link, one end of which is worked by an eccentric, and the other end held in position by a rod connected to a *concentric* disk on crank-shaft.

Proper hand-gear to be arranged for changing and marking the points of cut-off, and for holding the link in position.

CYLINDER-HEAD.

Upper cylinder head to be cast double-shell and ribbed between shells; head to be turned and polished; head to be recessed for nut of piston-rod and for heads of follower-bolts.

Two wrought-iron eye-bolts to be fitted for lifting head, and set screws fitted for starting off the head, all to be finished.

BED-PLATE OR FRAME.

Bed-plate or frame to be of cast-iron, in one piece; to be hollow, of the box form of section, and not less than 16 1-2 inches in depth, with all the necessary passage-ways for water, bosses, and nozzles or flanges for pumps, pillow-blocks, etc., and flanges or lugs for bolting in place.

A raised surface or flange for the condenser, to be cast on to receive flange of condenser.

The whole lower surface and all surfaces for flanges, pumps, hand-hole plates, pipe connections, etc., to be planed.

A light cast-iron pan to be fitted under crank-shaft to receive oil and drip from journals.

CONDENSER.

The surface-condenser will be set on the starboard side of engine, and to be arranged to pass the water of condensation through the tubes, and to have a cast-iron shell 1 1-8 inches thick, well-ribbed and strongly bracketed, to serve as the support of that side of the engine-frame; to have the necessary seating for engine frames cast on; to be cast with all proper man and handholes, seats for pillow-blocks, nozzles, valves, flanges and lugs for all necessary connections and attachments; all bearing and joint surfaces to be planed. Suitable bonnets to be fitted for access to all valves, tubes, etc.

Condenser to be fitted with horizontal tubes of yellow metal, and tinned both inside and outside, 5-8 or 3-4 inch diameter; tubes to have not less than 1,200 square feet of condensing surface; tube plates to be of cast-iron not less than 1-4 inch thick, planed on all joint surfaces, and bolted in place with composition standing bolts; tubes to be packed with "Allen's" wood or patent paper packing, or other approved packings.

If the length of the tubes should render it necessary, there is to be an intermediate tube plate near the middle of the length of the condenser. The tubes to be arranged in nests or sets, so that the refrigerating water will pass three times through the tubes.

The condenser to have suitable nozzle for attaching injection pipes, to convert it to a jet-condenser, if necessary.

There is to be fitted to the condenser a screw valve and pipe 1 1-2 inch diameter, with composition valve, valve seat and screw, connecting salt water with the fresh, as a supplemental feed-valve.

There is also to be fitted to the condenser a 4-inch copper injection-pipe and composition cock or valve, 4 inches diameter, with internal "rose-pipe," for use as a jet condenser; a perforated scattering-plate of cast-iron to be fitted above the tubes; also to be fitted a small connecting air-pipe and valve from top of condenser to air-pump.

AIR-PUMP.

To be a trunk-pump, having a working capacity of 3,400 cubic inches; to be lined with composition, and fitted with composition bucket and trunk; valve seats to be of grating form, of composition, with composition guards and studs and pure rubber valves.

The foot and delivery valve seats and guards to be of composition, and valves of pure rubber; valves to be located as directed.

HOT-WELL.

A cast-iron hot-well to be fitted to air-pump, of such form as may be determined, and to be

carried up at least 30 inches above load water-line, with 9-inch delivery valve and pipe of copper connecting with the main outboard-delivery valve.

OUTBOARD-DELIVERY PIPE.

Outboard-delivery pipe to be of copper, 9 inches diameter, of thickness No. 8 wire-guage; outboard-delivery valve to be a poppet-valve, 9 inches diameter, with composition valve, valve seat, and stem, and to be fastened to ship by 7-8 inch yellow metal bolts, passing through a composition ring on outside of ship.

CIRCULATING-PUMP.

Circulating-pump to be an independent steam-pump, of approved pattern, equal to at least 12 inches diameter and 15 inches stroke; pump lined with composition, and to have piston and rod, valve seats, stems, and guards of composition; steam-cylinder to be same diameter as pump; pump valves to be of best India rubber.

The side-delivery pipe for the circulating-pump to be of copper, No. 10 wire-gauge, with valve at side of ship fitted in same manner as the side-delivery valve for air-pump.

To the suction-pipe of the circulating-pump there is to be a branch suction-pipe of lead, 5 inches diameter, with proper shut-off and foot-valves; these valves to be so located as to be

readily seen and examined in reference to any leakage through into the bilge; the screw-valve or cock to have an attachment for locking it fast, so it can never be opened but under the direction of the chief-engineer.

AIR-PUMP BEAMS.

To be made of two wrought-iron plates 8-8 inch thick by 11 inches wide near main centre; main centre to be fastened to beams by distance-flanges firmly bolted; journals of main centre (of wrought-iron), 3 1-2 inches diameter by 4 1-2 inches long; short-end journals, 2 inches diameter by 2 1-2 inches long, or if but one journal, 3 inches diameter and 3 1-2 inches long; and long-end journals, 1 3-4 inches diameter by 2 1-4 inches long; additional journal for working feed and bilge-pumps.

PISTONS.

Pistons to be of cast-iron, double shell, properly ribbed, with cast-iron follower fastened by wrought-iron bolts screwed into brass nuts; follower to be accurately turned and scraped on the rings and piston, and furnished with two eye-bolts properly fitted for lifting; cast-iron packing rings in two thicknesses, accurately turned, fitted, and scraped, and set out with approved steel springs.

PISTON-ROD.

To be of mild steel, 3 5-8 inches diameter,

fastened to piston by nuts properly secured.

FEED-PUMP.

To have one feed-pump, with a working capacity of not less than 270 cubic inches, and fitted with composition plunger, valve and valve-seats, and to be worked as may be determined.

Pump to have an air-vessel, and fitted with a by-pass valve, so that the pump can be worked full at all times.

BILGE-PUMP.

To be same size and fitted in same manner as feed-pump, except that the valves are to be of India rubber, seating on composition gratings, with composition guards and stems; there will be no by-pass valve to this pump.

THROTTLE-VALVE.

To be a double poppet-valve, equal to a diameter of pipe of 8 1-2 inches; valve, valve-seat, and stem of composition; to be arranged for working by a lever readily and conveniently, with arc and set-screw for fastening at any point.

CROSS-HEAD.

To be of wrought-iron, well finished, and fastened to piston-rod with cross-key or forged solid with rod; journals 3 1-2 inches diameter and 4 1-4 inches long.

Bearing-gibs to be of lignumvitæ or composi-

tion, lined with soft metal, and have a bearing-surface of not less than 60 square inches ; gibs to be so made that they can be readily adjusted or removed without disconnecting engine.

SLIDE-VALVE STEMS.

To be of mild steel ; that for main valve to be 2 inches diameter, and for cut-off valve 1 6-8 inches diameter ; stuffing-boxes and glands for stems to be bushed with composition.

ECCENTRICS AND RODS.

There are to be two eccentrics for working the main valve by a "Stephenson" link, connected thereto by proper rods.

For working the cut-off valve, there is to be one eccentric connected by a proper rod to one end of a link, and the opposite end of the link to be held in position by a proper rod in connection with a *concentric* disk on the crank-shaft ; this link to be adjusted by a suitable hand-lever working in or against an arc, the arc to be marked off to the different points of cutting-off.

Eccentrics to have a large bearing-surface ; straps of composition, well ribbed.

Eccentric-rods of wrought-iron, well fitted and connected to links in such manner that they can be adjusted for wear ; link and pins to be case-hardened, and link blocks of composition.

CONNECTING-RODS.

Connecting-rod to be of best wrought-iron, forked at the cross-head end, and handsomely finished; length to be about 6 feet 10 inches between centres; crank-end neck 4 inches diameter, fork-end neck 3 5-8 inches diameter; boxes to be of best composition, and suited to cross-head and crank-pin journals, and to be secured by wrought-iron straps with gibs and keys; keys to be secured by steel set-screws; crank-pin boxes to be of phosphor-bronze.

MAIN PILLOW-BLOCK.

Main pillow-blocks to be cast with bed-plate, and to be fitted with composition upper boxes and phosphor-bronze lower boxes.

After-journal to be 8 3-4 inches diameter by 13 inches in length; forward journal 7 inches diameter by 10 inches in length; pillow-block caps for after journal 2 3-4 inches in thickness, by 11 inches in width, and for forward journal 2 1-2 inches in thickness by 8 inches in width; the after cap to be held down by two bolts 2 5-8 inches diameter, forward caps by two bolts 2 1-4 inches diameter; caps to be made to clasp or lip over ends of block.

Boxes to be babbited; bolts and nuts finished, and nuts fitted with proper keepers.

CRANK-SHAFT.

To be of wrought-iron, of locomotive form, 19 .

forged in one piece ; or shaft, cranks, and pins to be in separate pieces, forged together, and keyed ; if made in separate, crank-pin to be of steel.

After crank-shaft journal to be 8 3-4 inches diameter by 13 inches in length, forward one 7 inches diameter 10 inches in length ; crank-pin journal 6 1-2 inches diameter and 9 inches in length; collars on after journal, but none on forward journal.

LINE-SHAFTS.

Line-shafts to be of wrought-iron, in three lengths; smallest diameter 8 1-2 inches; through stern-pipe to be covered with a composition sleeve, finished 3-8 inch in thickness, put on hot, and properly fastened.

Line-shaft couplings to be plate couplings of cast iron, accurately turned and fitted, and fastened together with six bolts 1 5-8 inches diameter, and a steel cross-key or feather; bolts to be turned and accurately fitted to couplings.

Coupling of crank-shaft to line-shaft to be a pair of cast-iron wheels or disks, with two wrought-iron driving-pins, properly fastened in the forward or counterbalance wheel, and working free on composition bearing-plates in after-wheel.

The thrust-bearing to be on forward length of line-shaft and to be a collar thrust, having

seven collars 1 1-4 inches by 1 1-4 inches, properly fitted to boxes, or such other thrust-bearing as may be approved.

THRUST PILLOW-BLOCK.

Thrust pillow-block to be of cast-iron, with composition boxes and phosphor-bronze collar plates, well fitted; an oil reservoir to be on cap, and the cap and boxes well locked to the block to receive the thrust.

In addition to the cap and holding-down bolts, there will be fore and aft fastenings to hull to receive the forward thrust.

LINE-SHAFT PILLOW-BLOCKS.

To be of cast-iron, with cast-iron cap, and fitted with composition box for lower half of journals; caps and boxes to be accurately bored and fitted, and the blocks well fastened.

COUNTERBALANCE-WHEEL.

There will be a counterbalance-wheel of cast iron, fastened upon the after end of crank-shaft next to after crank-journal, which also form one wheel or disk of the coupling; to be about 4 1-2 feet diameter or as large as the space will permit, and cast with mortises on the periphery for turning the engine with a pinch-bar.

SCREW-PROPELLER.

To be of cast-iron 4-bladed, 9 feet 9 inches dia-

meter and about 30 inches in length, fore and aft, and 15 1-2 feet average pitch.

Propeller to be bored, and keyed upon shaft by a feather-key and a cross-key; template of the bore of the eye to be supplied with the engine.

A water-tight composition cap to be fitted over the end of shaft and fastened with composition tap bolts to end of hub; also composition caps over ends of cross-key.

LINING OF DEADWOOD.

The deadwood to be bored to receive the stern-bearing and inboard stuffing-box; then lined with a lead pipe 1-4 inch thick, well and carefully drawn to fill the opening, and flanged over on both ends and well nailed with composition nails.

STERN-BEARING.

To be of composition, and whole length 3 feet 8 inches; the part projecting abaft the stern-post to have a lip or cap covering the forward edge of propeller-hub 1 inch, to prevent ropes getting jammed between hub and bearing.

Stern-bearing to have a vertical flange against after side of stern-post 3 feet 9 inches in length, and side or cheek-plates of the same vertical length and running forward about 2 feet 10 inches; vertical flange against after side of stern-post to be fastened with large wood screws

having nuts on after ends, and the cheek-plates to be carefully fitted to form of stern and fastened with bolts driven through and through the deadwood and riveted; stern-bearing to be fitted with lignumvitæ staves, in a sleeve of composition the whole length, in the usual manner.

INBOARD STUFFING-BOX.

To be of cast-iron, well fitted to deadwood lining, and to be 21 inches in length in deadwood, and to be lined with lignumvitæ staves in a composition sleeve, same as stern-bearing; to be well fastened to the deadwood with wood screws, with nuts screwing upon flange; also with a fore and aft flange well fastened to keelson.

Packing space 12 inches deep; gland to be accurately bored and fitted to shaft; packing to screw down on a loose ring, placed at bottom of stuffing-box, to keep staves in place.

SEA AND KINGSTON VALVES.

There will be screw-valves having cast-iron chambers, and composition valves, seats, stems, and glands applied to every opening through vessel (for pipes) which is below the load water-line.

Valve for circulating pump, 7 inches diameter; valve for steam-pump, 3 inches diameter; Valve for injection, 4 1-2 inches diameter;

Valve for bottom blow, 2 1-2 inches diameter; Valve for injection, circulating pump, and for steam-pump to have each a strainer on outside of vessel, made of 3-16 inch copper, and fastened with composition screws or nails.

These valves to be fastened to hull by composition or yellow metal wood screws, and the openings through vessel lined with a copper sleeve, well fitted and fastened.

Note.—The seats of *all* poppet-valves to be secured in place either by riveting or set-screws.

OUTBOARD DELIVERY

Outboard-delivery valve to be a poppet-valve, 9 inches diameter, with cast-iron chamber and composition seat, valve, stem, and gland, with handle for tricing up.

BILGE-VALVE AND PIPE.

Bilge-injection valve to have a cast-iron chamber, with composition seat, valve, stem, and gland.

Valve to be 3 1-2 inches diameter, and connected to condenser as near the top as possible; the main portion of the pipe to be of copper, No. 14 wire-gauge, and the lower end of lead, with a suitable box-strainer.

DONKEY BOILER.

There will be a donkey boiler, of locomotive

style, with semicircular water bottom under ash-pit.

Boiler 34 inches diameter of shell, furnace 3 feet long by 28 inches wide ; to have 34 iron lap-welded tubes 2 3-4 inches diameter, by 6 feet 6 inches in length ; there will be a steam dome 18 inches diameter by 20 inches in height, cast-iron front to furnace, and door properly fitted, and back end of smoke-box closed with a cast-iron plate, having a door properly hung and fastened, for access to tubes.

Boiler to be fitted with the necessary grate-bars and bearers, safety-valve, steam-gauge, gauge-cocks, and all other appurtenances.

Boiler to be made of the best material throughout, and tested by hydrostatic pressure to 120 pounds per square inch.

There will be fitted a smoke-chimney, 15 inches diameter by 16 feet in length, with bands, guys, etc., complete.

Where smoke-chimney passes through promenade deck there will be fitted a proper cast-iron collar, with a cover to shut the opening when the smoke-chimney is unshipped; there will be a suitable casing of galvanized iron around chimney and smoke-box, to protect wood work.

DONKEY BOILER FEED.

For feeding the donkey boiler there will be furnished, and fitted with all necessary pipes

and valves, a No. 1 direct-acting steam-pump, to be located as may be directed.

HOISTING ENGINE.

There will be a hoisting or buoy engine furnished by the Light-house Board, of the regular pattern, about 10 1-2-inch cylinder and 10 inches stroke, which is to be located, erected, and fastened on forward deck next forward of deck-house, with all pipe connections of wrought-iron and stop-valves of composition; there will be a pan of sheet-lead, 1-8-inch thick, fitted under the engine to receive all dripping of oil and water.

MAIN BOILER.

Boiler to be an overhead return-flue boiler, 9 feet 10 inches front and 9 feet 10 inches diameter of waist, and 23 feet in length, with water-leg furnaces 6 feet 10 inches long; main flues, three of 13 1-2 inches diameter and two of 16 1-2 inches diameter, for each furnace; return-flues in two tiers, seven flues 12 1-2 inches diameter in each tier; flues to be welded and drawn-flues.

Steam-chimney shell 6 feet 9 inches diameter, and flue 45 inches diameter; height of steam-chimney above shell 10 feet 6 inches.

Main steam-chimney flange, the waist flange, and all longitudinal seams of circular part of shell of boiler and of shell of steam-chimney

and lower part of legs to be double riveted.

Flat work braced not exceeding 7 1-2 inches centre to centre, with 7-8 inch socket-bolts, and other parts braced to corresponding strength.

Socket-bolts in steam-chimney to have nuts and washers, and not to exceed 11 inches centre to centre on the flue side.

The thicknesses of iron and dimensions of the several parts to be as shown on the accompanying drawing, and as follows:

Circular part of shell 5-16 inch thick; lower part of legs 3-8-inch, and double riveted; shell of steam-chimney, No. 2 Birmingham wire-gauge; steam-chimney flue of mild steel 3-8 inch thick; the fire-box or furnace plates of mild steel, No. 2 wire-gauge.

Flues of No. 3 and No. 4 wire-gauge; heads of shell, flat work, and connections to be No. 2 wire-gauge.

No part of any plate or sheet to gauge less in thickness than required by the drawing and specification.

The iron for the boiler must be of the best quality throughout—no puddled iron will be accepted.

All necessary man and hand-holes to be cut, and fitted with reinforcing-rings, plates, guards, and bolts.

All doors to be double, or to have a plate lining properly fitted and drilled.

Boiler to be proved by a hydrostatic pressure of 65 pounds per square inch, and to sustain the same satisfactorily, after which it is to be painted with two coats of brown oxide paint.

The rivets throughout the boiler to be of iron of the best quality, and to be of a diameter and pitched at a distance suited to the thickness of the plate-iron.

BOILER SUPPORTS AND FASTENINGS.

For the support of the boiler, chairs of cast-iron for the fire-box portion of the boiler will be required to be cast upon plates inclosing the ash-pan—that is, the sides of the ash-pit are to be of cast-iron, set outside the ash-pans; the waist to rest on two cast-iron saddles properly fastened.

ASH-PANS.

Under the furnaces are to be cast-iron ash-pans, made in one width for each furnace, bottom of pans, 5-8 inch thick and flanges 1-2 inch thick; to be properly fitted against the chairs which support the boiler; ash-pans to have a long beveled front flange projecting at least fifteen inches from front of boiler to catch dropping fire and cinders from doors.

GRATE-BARS.

Grate-bars to be of cast-iron, in two lengths, 6-8 inch thick on the face, and 5-16 inch at

lower edge, with 5-8 inch air-spaces; fitted with all necessary bearing-bars, slicing-bars, etc.

FELTING

Main and donkey boilers and steam-chimney to be covered with hair-felt 1 1-2 inches thick, with backing of wool felt, or galvanized sheet-iron jacket, as may be directed, all properly secured in place; main and other steam-pipes to be covered with hair-felt 1 inch thick, with backing of canvass, well painted.

Note.—The felting is not to rest upon the iron of the boilers, but to be supported upon iron flanges or bands, leaving an air-space between the felting and boilers.

BOILER ATTACHMENTS.

There is to be attached to the boiler one steam stop-valve, 8 1-2 inches diameter; one safety-valve, 7 inches diameter, having composition valve and seat, pins, and jaws, with connections to engine-room, and copper escape-pipe 18 feet in length; one bottom blow-valve, 2 1-2 inches diameter; one surface blow-valve, 2 inches diameter; one screw stop-valve for steam-pump; one screw stop-valve for circulating-pump; and one screw stop-valve for hose connection fresh-water pipe.

All these valves to be of composition, with composition glands and stems.

Also four brass gauge-cocks, with drip-pan and pipe; one glass water-gauge, 16 inches in length; and one salinometer cock.

SMOKE-CHIMNEY.

To be 46 inches diameter and 26 feet in height, made in 4 courses; to be flush-jointed with bead-iron bands at the butts, 3-inch angle-iron band at upper end, and band 2 1-2 inches by 3-8 inch at lower end.

Two lower courses of iron, No. 10 wire-gauge, and two upper courses of iron, No. 12 wire-gauge; chimney to be fitted with a proper damper, having connections leading to engine-room for opening and closing.

A casing to be fitted on upper deck around the lower part of smoke-chimney and where the steam-chimney comes through the deck, to be made of iron, No. 10 wire-gauge, fastened to deck-combing with angle-iron; also, a neat umbrella above casing, to permit ventilation.

Chimney to have twelve stays of wire rope 9-16 inch diameter, with proper connections at chimney and at deck.

Chimney, casing, and umbrella to be painted with two coats of brown oxide paint on both sides; also, a third *outside* coat of such color as may be directed.

STEAM-PUMP.

One steam-pump, No. 4, with brass water-

cylinder and piston, to be 5 inches internal diameter; to be furnished and fitted with all necessary pipes, cocks, and valves, and arranged to be used as a fire-engine, to supply distilling apparatus, to pump boiler, and to pump from bilge.

Also, 150 feet best rubber hose, in three lengths, with couplings, one brass and one leather blanch-pipe.

All water-pipes of pump to be of copper; steam and exhaust-pipes of wrought-iron.

Exhaust-pipe to have a branch leading to the condenser and one to the atmosphere, with proper valves for exhausting in either direction, as desired.

There is to be a brass hose-connection to pump-delivery pipe at main and upper decks, with shut-off valves.

DISTILLING APPARATUS.

A distilling apparatus or condenser, capable of producing 250 gallons water per day, to be furnished and fitted with all necessary cocks, valves, and pipes; water-pipes to be of copper, steam-pipes of wrought-iron; distiller to be connected by pipes and valves with water-tanks; distiller to be located as may be directed.

ASH-SHUTE.

Two ash-shutes of galvanized sheet-iron, to

be furnished and fitted as may be directed, for discharging ashes over the side of vessel.

DECK-SCUTTLES.

There are to be furnished and fitted in deck eight cast-iron coal-scuttles, to have close covers and gratings arranged in the usual manner; frames bored and scuttles turned.

VENTILATORS.

There are to be two iron ventilators to fire-room, 18 inches diameter, with bell-mouthed revolving-caps fitted to turned and bored rings; to have arrangements fitted for hoisting ashes; and to be painted with two coats brown oxide paint inside and outside; also, a third coat outside, of such color as may be directed.

CAST-IRON FLOORING, Etc.

The whole of the fire-room floor and alongside the boiler for a distance of about 2 1-2 feet to be covered with cast-iron flooring-plates, rough surface, and 5-8 inch thick in body, laid upon a course of bricks and hydraulic cement; the deck over fire-room to be covered with cast-iron grating, open for ventilation.

In the engine-room all the space around the engine is to be covered with cast-iron grating; such brass railings around engine to be furnished and fitted as may be required.

There are to be furnished and fitted a wrought-

iron ladder with cast-iron treads, from engine-room to hold, with brass railing; also, one rung-ladder, from deck to fire-room, with iron-railing, all properly fitted and fastened.

EYE-BOLTS.

All necessary eye-bolts for lifting and handling the various parts of the machinery to be furnished and fitted.

PIPES AND BOXES.

All water-pipes for engine and boiler to be of copper, of proper thickness; main steam-pipe of copper, 3-16 inch thick and 8 1-2 inches diameter, with suitable slip-joint; the flanges of all copper-pipes to be of composition.

All boxes, except where otherwise directed, to be of best composition.

STEAM-HEATERS OR RADIATORS.

For heating pilot-house there will be furnished and fitted a wall-coil of brass-piping, having not less than 16 feet of radiating surface; the steam and drain-pipes from this coil must be of brass or copper for at least 8 feet distance from the pilot-house.

For inspector's cabin there will be a pedestal radiator of not less than 60 feet surface; for the after cabin below, a pedestal radiator of not less than 60 feet surface; and for the forecastle, a radiator having not less than 40 feet

radiating surface; all to be fitted with necessary steam and drain-pipes and valves.

The steam-pipes to be so arranged as to take steam from either main or donkey-boiler.

A steam-pipe and valves must be arranged for heating water in the bath-room.

WATER-TANKS.

There will be furnished and fitted two wrought-iron water-tanks, to contain not less 300 gallons each; to be made of iron, No. 6 wire guage, with the necessary man-holes and plates; they are to be connected together by a wrought-iron pipe 2 inches diameter, with stop-valves and the necessary air-pipes.

There will also be a pipe from the deck to this connecting-pipe, with a suitable composition deck-screw at deck; also, a 3-4 inch stop-cock near the bottom of each tank for draining, and a pipe from the connecting-pipe to the hand-pump in the kitchen for drawing water from the tanks; tanks to be well fastened in place.

OIL, WASTE, AND TALLOW TANKS.

There will be furnished, fitted, and fastened in place, as may be directed, one iron oil-tank, to contain thirty gallons, with lock cock; also one portable oil-tank of copper, to contain fifteen gallons, with cover, cock, and drip pan; one sheet-iron waste tank, to contain sixty

pounds waste; and one sheet-iron tank, to contain one hundred and forty pounds tallow; all to be located as may be directed.

STEAM-WHISTLE.

There will be furnished and fitted one brass steam-whistle, not less than 6 inches diameter of bell, with stop-valve at the boiler, and wrought-iron steam pipe to extend at least 12 feet above deck, with all necessary arrangements fitted for blowing it from the pilot-house.

GONG, BELLS, Etc.

Engine-room to be furnished with one gong, 12 inches diameter, with brass shield, and tube to return sound to pilot-house, and one "jingle" bell, both arranged with proper wire and pulls for ringing from the pilot-house, and the gong also to ring from the after-deck; also, a brass speaking-tube from pilot-house to engine-room.

SALINOMETER AND GAUGES.

There will be furnished and fitted one salinometer, with all necessary pipes, valves, hydrometers and thermometers.

Engine-room to be fitted with one 6 1-2 inch nickel-plated steam-gauge, one similar vacuum-gauge, and one counter and marine clock combined, with all their connections and attachments; pipes to be of copper.

Also, for fire-room, one 6 1-2 inch iron case steam-gauge, and one piece 1 1-2 inch rubber hose about 18 feet in length, with proper stop-cock, for wetting down ashes.

HOISTING ASHES.

For hoisting ashes there are to be furnished two suitable iron ash-buckets, to be arranged with the necessary eye-bolts and blocks and falls, properly fitted in the fire-room ventilators.

OIL-CUPS AND WASTE-PIPES.

There are to be brass oil-cups, automatic or plain, as may be directed, fitted to all journals; also, one piece of rubber hose, 1 1-4 inches diameter, fitted with valve and pipe, for supplying water to any of the journals which may require it.

PAINTING.

All the machinery not finished or polished, to have three coats of lead or zinc paint, the last coat of such color as may be directed, and to be covered with a good coat of clear white varnish.

DUPLICATE PIECES.

There will be furnished and fitted one extra pair crank-pin boxes; three follower bolts and nuts for piston and two for air-pump; three cylinder head bolts; one cross-head gib; one hundred extra tubes for condenser; two hun-

dred and fifty (250) packing for condenser tubes; one complete set of rubber valves for air-pump, circulating-pump, steam-pump, and bilge-pump; one feed-pump valve, and seat; twenty extra grate-bars; three water-gauge glasses; twenty-four 5-8 inch joint bolts and washers; one man and one hand-hole plate complete; six (6) hydrometers, and three (3) thermometers.

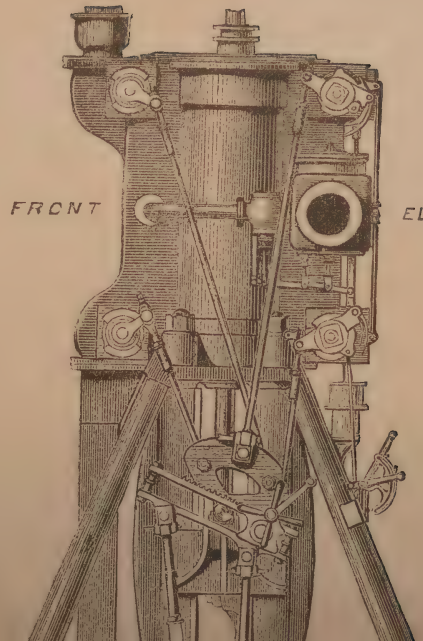
TOOLS.

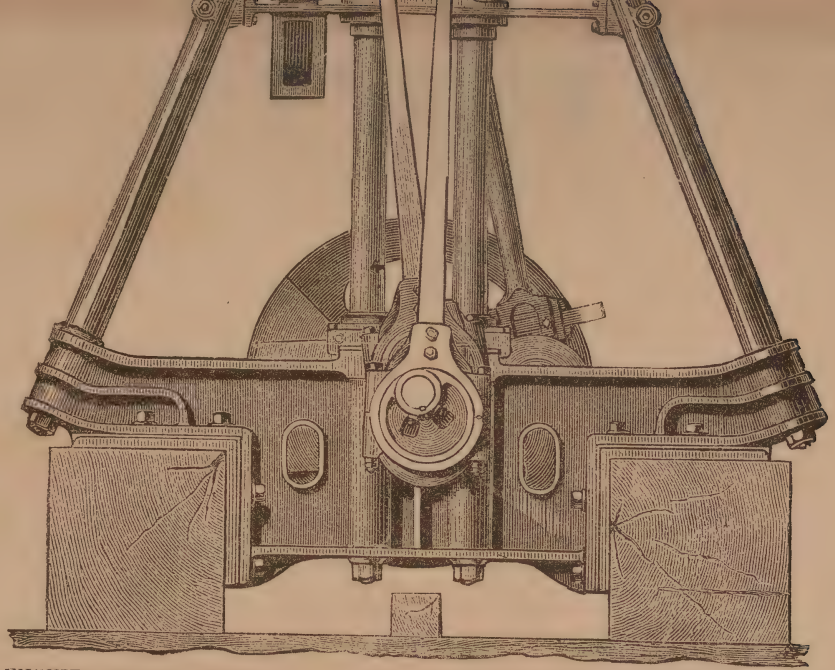
There are to be furnished one complete set fire-room tools; one complete set of S-wrenches for engine; one key wrench; three screw wrenches; two pipe wrenches; two copper oil measures; one complete set of brass oil-cans, with drip-pan; one 6-inch vise and bench; two pairs iron blocks and falls; three hand hammers; two sledges; one copper hammer; one drill crab; one pall wrench and drill brace, with six assorted drills fitted; one pair calipers; one hack saw; four chipping chisels; two cape chisels; two calking tools; one pinch bar; one dozen files, assorted, with six handles; two flue brushes and handle; three boiler-scaling tools; one centre punch; one set stocks, taps, and dies to suit threads of engine bolts; one socket wrench for piston follower, and one for air-pump follower; one two-foot rule; and one chest carpenters' tools complete.

ENGINE OF THE STEAMER "VERA CRUZ."

THE steamship *City of Vera Cruz* belongs to the New York and Mexican Mail Steamship Company. She is a wooden ship, and this fact accounts for the rather remarkable form taken by the engine's bed-plate. The engine has a single cylinder, 4 feet diameter, the stroke of the piston being 6 feet. Both the vertical and diagonal supports of the frame are of cast-iron, with a wrought-iron bolt through each. Wrought-iron journals or rings are shrunk on the bottoms of the vertical columns. These have threads cut on them, and form the main bearing bolts, a very singular device. The pumps are all worked by an auxiliary engine. The condenser is a separate casting, located between the engine and the boilers in the centre of the ship. A centre for a beam is fixed on top, and to the starboard side is bolted the steam cylinder of the auxiliary engine, while all the pumps are on the port side. The beam extends across the top of the condenser. The feed-water from the hot-well is passed through a cast-iron filter 10 feet long, 6 feet wide, and 3 1-2 feet deep, the feed entering at one end and discharging at the other. There are five wooden frames fixed across the filter. Heavy woollen felt blankets are nailed to these frames, protected by a wire netting at each side from

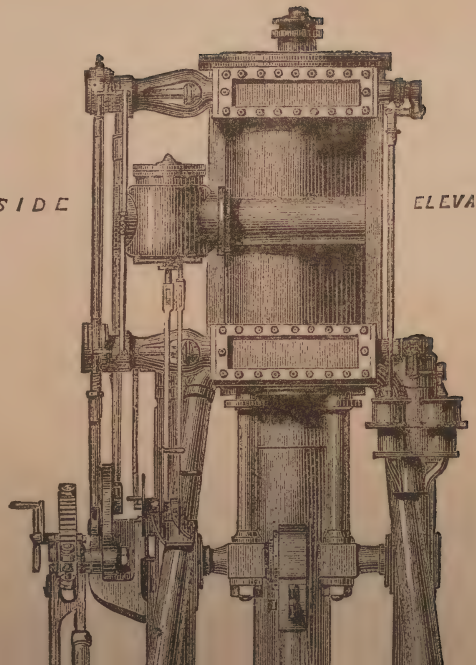
FRONT ELEVATION

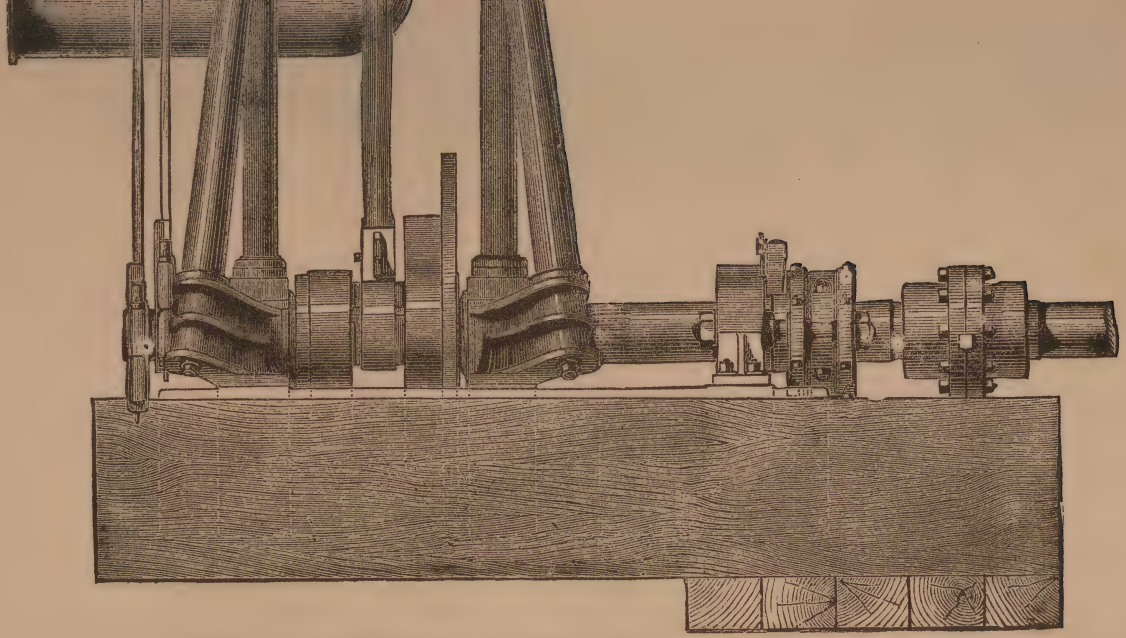




ENGINES OF THE AMERICAN S.S. "VERA CRUZ"—FRONT ELEVATION (fig. 41, p. 226.)

SIDE ELEVATION





ENGINES OF THE AMERICAN S.S. "VERA CRUZ"—SIDE ELEVATION, (fig. 42, p. 227.)

the coke with which the filter is filled up. The valve gear was designed by Mr. George Reynolds, of New York, is of the Corliss type, and to judge by the diagram—which is the reproduction, precisely half-size, of an actual diagram—it works very well. The drawings so far explain themselves, that further description is, we think, unnecessary.

BOILERS OF THE "VERA CRUZ."

The boilers, two in number, are of a very unusual type. The fact that they have been used for two years with perfect success is fresh testimony to the value of the vertical system. They were designed by Mr. Peek, and constructed by Messrs. Quintara and Murphy. Each boiler is 21 feet 3 inches high, and 13 feet, 1 1-2 inches in diameter. In it are six furnaces, giving a grate area of 89 square feet. There are in each 472 tubes, 2 1-2 inches diameter ; eighty of these are stay tubes, 3 1-6 inches stroke. The wetted surface of these tubes is normally 8 feet long, giving a surface of 2,285 feet, while the furnace surface is 360 feet; the total heating surface in the two boilers is, therefore, 5,290 feet; the total length of the tubes is 11 feet; the furnaces are 4 feet high, and the shell plates are 3-4 inch thick, double riveted with butt and strap joints. The heads of the boiler are of 1-2 inch plate,

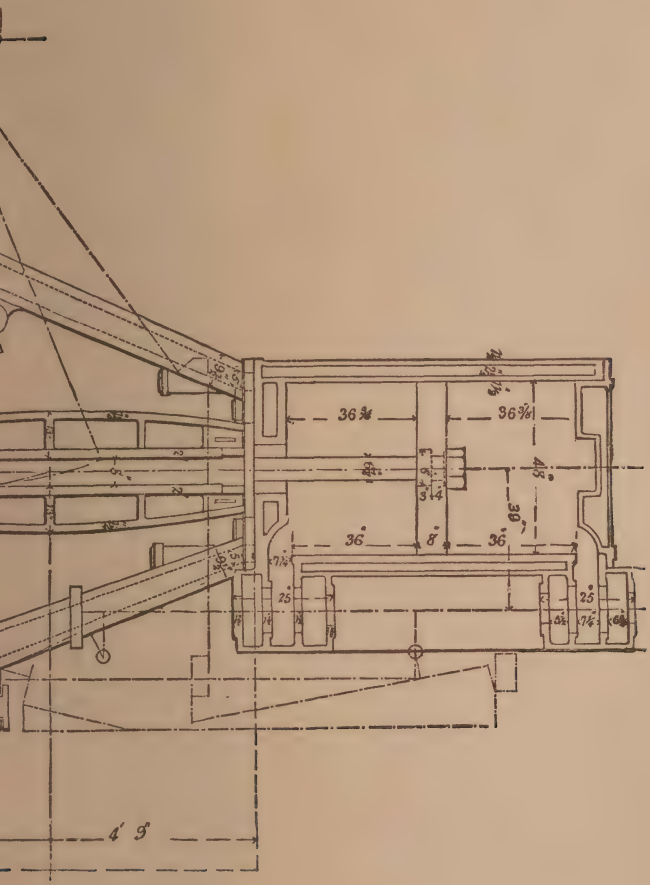
double riveted, with lapped joints; the stays are 6 inches apart; the tube plates are 1-2 inch thick; the furnace plates are of steel, 3-8 inch thick; the central fire doors are 16 inches and the side doors, 26 inches wide. The great height of the furnaces ensures perfect combustion, and the fires run a long time without being cleaned. The pressure usually carried is 75 pounds, but the boilers are loaded to 90 pounds. The temperature in the base of the funnel does not exceed 400 degrees, and the steam is thoroughly dried and moderately superheated.

The *City of Vera Cruz* is 276 feet long, 37 feet beam, and 26 feet deep. Her tonnage, by the American standard, is 1,874; her usual consumption of hard coal is, we understand, 22 tons per day, and with this the ship steams about 13 knots on 18 feet of water.

ENGINE OF THE STEAM-SHIP "HUDSON."

BUILT BY MESSRS. PUSEY, JONES & CO.

For some years a line—known as the Cromwell line—of steamers has been running regularly from New York to New Orleans, a distance, in round numbers, of about 1,800 knots. The engines of these steamers have, therefore, to work day and night for considerable periods. Three of the vessels are known as the *New Orleans*, *Knickerbocker*, and *Hud-*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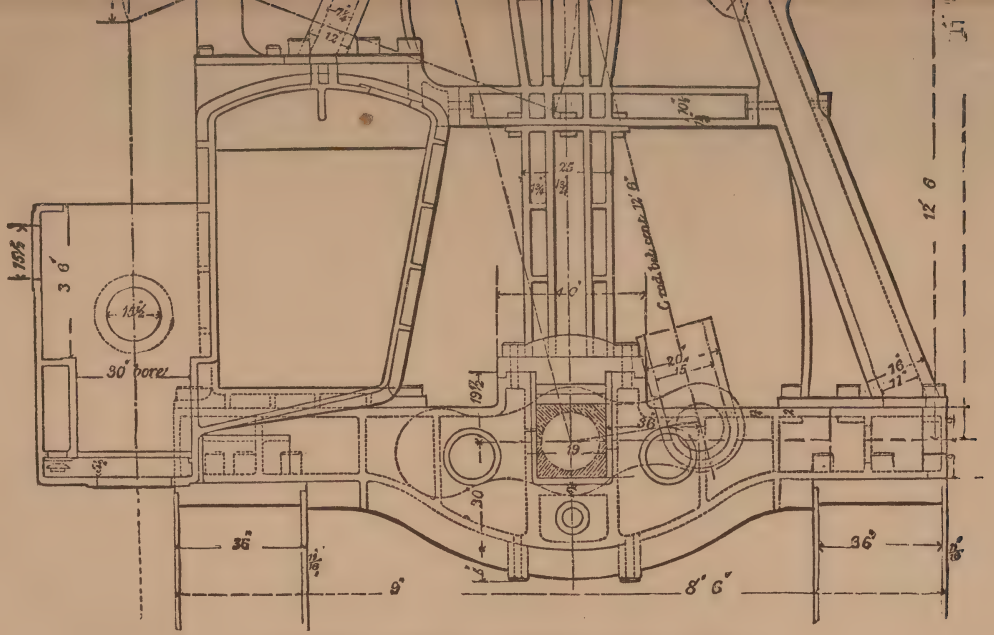


ENGINES OF THE S.S. "HUDSON," (fig. 43, p. 228.)

son. We shall confine our attention to the most recently built of the three, viz., the *Hudson.* She is an exceedingly handsome type of sea-going screw steamers, and it will be granted, we think, that if machinery of a given kind is successfully used to propel her, it may be used with equal success in the case of other ships. In a word, an experiment conducted to a successful issue on board such a ship as the *Hudson*, carries a weight which it would not possess if the ship and her engine were smaller, or made shorter voyages in less tempestuous seas.

The *Hudson* is propelled by one single cylinder surface-condensing engine, with an over head inverted cylinder, the stroke being 6 feet, and the diameter of the piston 48 inches. The working pressure is 90 pounds absolute, or 75 pounds safety-valve load. There is no fly-wheel, but the weight of the crank, etc., is counter balanced by a back crank, as shown in the drawings. The valve gear is very peculiar. It will suffice to say that steam is admitted to and exhausted from the cylinder by four independent double-beat-poppet valves, worked by wipers on rocking shafts, and cams on the crank shaft. It was deemed expedient to get the sharpest possible admission and cut-off, and 90 pounds of steam is thrown on this 48-inch piston at each stroke in a fraction of a second of time, while the cut-off is literally as quick as

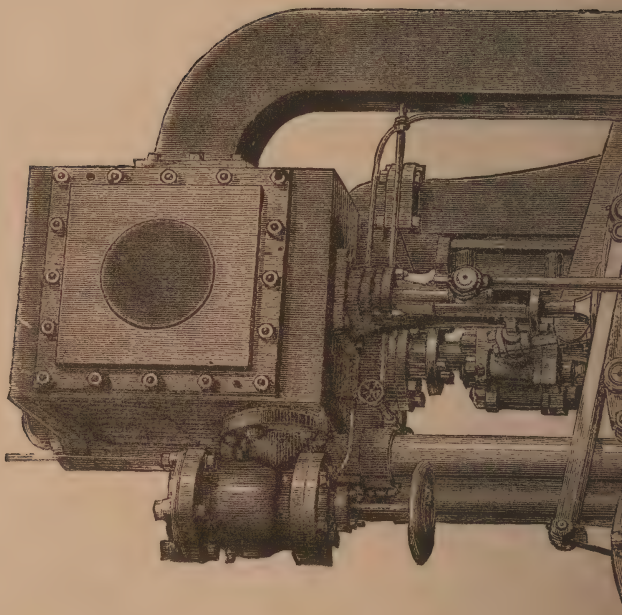
lightning, and quite different in this respect from anything that can be had with slide-valves. As they are accurately in equilibrio, and provided with dash-pots, the valve gear, complex as it appears, works in silence and without jar or vibration. In going into or out of port full steam is carried almost throughout the entire stroke, the throttle-valve being almost closed. The engine never sticks on the centre, and is handled with the utmost ease by a couple of men, notwithstanding its great size. Steam is in regular work cut off at from one-twelfth to one-fifteenth of the stroke. The area of a 48-inch cylinder is 1,810 square inches, and the strain brought to bear at the beginning of each stroke on the piston-rod of the *Hudson* is not less than $1,810 \times 90 = 162,900$ pounds, or over 72 tons. It is difficult to realize the fact that an engine like that of the *Hudson* can work, silently, at 60 revolutions per minute, or 720 feet of piston speed. On this point we cannot do better than quote the following passage from a letter concerning this ship, we have received from Mr. Buchanan Henry:

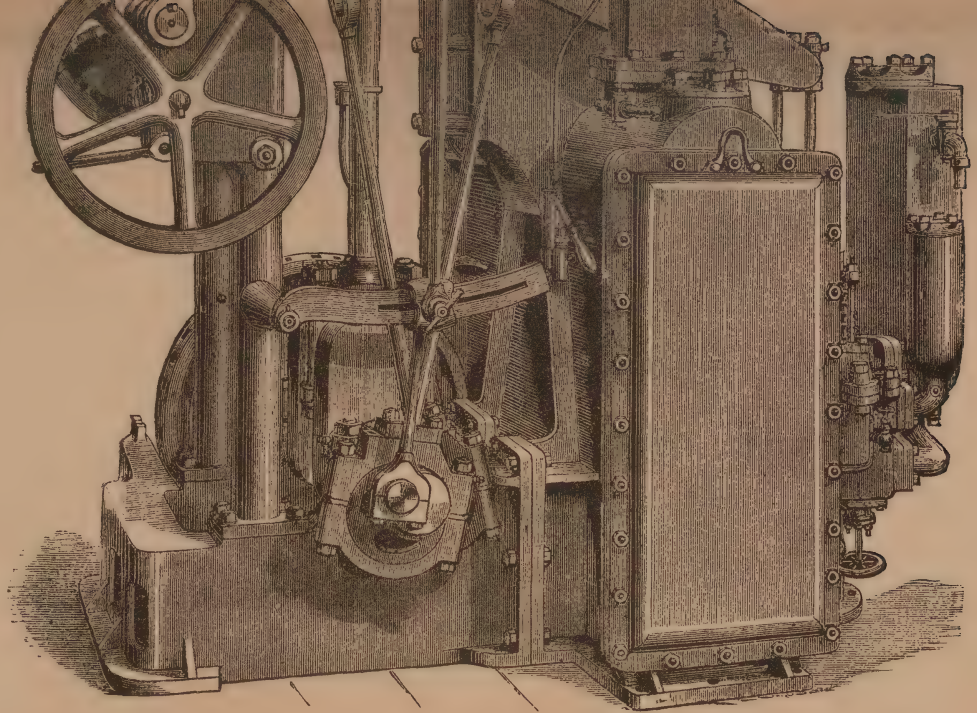
"Theoretically, most engineers would look for great vibration and unequal motion in an engine suddenly admitting steam of 90 pounds pressure upon the piston, then cutting off abruptly after the piston had only traversed five or six inches in six feet of stroke, and then dimin-

ishing the pressure progressively by expansion, until at the end of the stroke the terminal per square inch should not exceed five or six pounds absolute. Many would naturally expect that the hammer-like blow of such high steam upon the piston at the beginning, dying out to nothing at the end of the stroke, would rapidly tend to shake the engine itself to pieces, and strain the ship's hull. The answer is that, in the history of mechanical contrivances, it is often found that theory and practice are not on the most friendly terms. It is notably so in this instance. There is, in fact, less vibration or shake, I can safely say, in the *Hudson's* engine room than in that of any short stroke or compound steamship I have visited, and I have examined a number. Although you may be standing close to the ponderous 12 feet connecting-rod, making nearly 120 strokes per minute, you would hardly think the engine in motion but for seeing the long sweeping stroke, and hearing the clear sharp click of the expansion gear, as there is no sensible shock, jar, or tremor. This may be partly due to good workmanship, but not wholly, as no excellence in this respect would counteract any serious defect in design."

The comparative dimensions and power of these three vessels will be found in the table given on the following page.

Iron Vessels.	New Orleans.	Knickerbocker.	Hudson.
Indicated horse-power developed	—	780 to 860 H. P.	1,150 to 1,450 H. P.
Registered tonnage	1,440 tons	1,642 tons.	1,783
Length, breadth, depth	253x33x24	260x33½x22	294x34x23
Bulwarks, height	3 ft. 9 in.	3 ft. 9 in.	3 ft. 3 in.
When built and put on route	1872	1873	1874
Displacement with ordinary load	2,244 gross tons	2,519 gross tons	2,950 gross tons
Mean draught, loaded ordinary freight	18 ft.	17 ft.	17 ft.
Engine, Baird's single cylinder, poppet valve, long stroke, expansive	48 diam., 5 ft. stroke	44 diam., 6 ft. stroke	48 diam., 6 ft. stroke
Propeller, true screw	14 ft. diam., 20 P.	14½ ft. diam., 21 P.	15 ft. diam., 22 P.
Boilers, return tubular	Two boilers.	Four boilers.	Four boilers
Number of furnaces, and length	Ten; 6 ft.	Twelve; 5½ ft.	Twelve; 6 ft.
Width, length, and height	14 ft. 10 in.x12x14	9x12x12·4	9·6x13·8x12·6
Tubes, diameter, and length	536; 3 in.x9 ft.	532; 3½ in.x10 ft.	560; 3½ in.x11·8
Steam chimneys	14 ft. high, 6·6 diameter	12 ft. high, 5·6 diameter	13½; 5·10 diameter
Drums, two; one for two boilers	—	—	—
Pres. of steam above atmosp. and absolute	50 lb.; 65 absolute	66 lb.; 71 absolute	75 lb.; 90 absolute
Point of cutting off	$\frac{1}{6}$ to $\frac{1}{5}$	$\frac{1}{8}$ to $\frac{1}{11}$	$\frac{1}{12}$ to $\frac{1}{15}$
Vacuum	25 in.	26 in.	26 in.
Temperature of steam	327 deg.	340 deg.	370 deg.
Revolutions per minute, ordinary work	57 to 60	57 to 60	56 to 59
Revolutions, highest No. for one watch	70	70	69
Distance from New York to New Orleans, wharf to wharf	1,800 sea knots.	—	—
Average trip out, against current	6 days, 10 hours	6 days, 7 hours	6 days, 7 hours
Average trip back, with current	5 days, 17 hours	5 days, 14 hours	5 days, 14 hours
Shortest trip out	6 days, 8 hours	5 days, 20 hours	5 days, 21 hours
Shortest trip back	5 days, 12 hours	5 days, 6 hours	5 days, 10 hours
Greatest run in 1 day; no wind or current	310 knots	330 knots	335 knots
Coal in twenty-four hours (anthracite)	16 tons	17 tons	19 tons





MARINE ENGINES OF WM. CRAMP & SON'S SHIP & ENGINE BUILDING Co., (fig. 44, p. 233.)

MARINE ENGINE OF WM. CRAMP & SONS.

Among the comparatively few exhibits of marine engines at the Centennial, those of the William Cramp & Sons' Ship and Engine Building Co., of Philadelphia, occupy a prominent place. We illustrate the smallest of their exhibits, a single cylinder, high-pressure, surface-condensing engine. This class of engine has been largely introduced upon tug-boats running on the Delaware and other rivers, where paddle-wheels are generally abandoned for screws on tug-boats. As shown in the engraving, the point of cut-off is controlled by altering the stroke of the expansion-valve. It will be seen that the lower end of the expansion-valve stem terminates in a cross-head, working in guides. On the side of the cross-head is a pin on which is placed a link which descends as far as an oscillating segmental arm attached at one end to one of the main pillars forming the framing of the engine. To this arm, which is graduated, is attached the upper end of a link to which motion is given by a crank on the main shaft, as shown. The lower end of the link descending from the cross-head of the expansion-valve stem, slides upon the graduated arm, and may be locked in any desired position by means of the screw and handle shown; and by sliding it to and

fro, any desired degree of expansion may be obtained. The reversing gear consists of a hand-wheel, carrying a pinion on its shaft, which gears into a segment with internal teeth, and throws the lever attached to the link to and fro. The air-pump is worked in the ordinary way by back levers connected with the cross-head, which latter works on a slipper guide upon the main frame.

The diameter of cylinder of this engine is 20 inches, and the length of stroke 22 inches. With 59 pounds initial pressure in the cylinder, and a speed of 100 revolutions per minute, an indicated horse-power of 196 was developed on trial.

ENGINES OF THE AMERICAN STEAMSHIP LINE.

The hulls and engines of the American Steamship Company's four vessels — the *Pennsylvania*, *Ohio*, *Indiana*, and *Illinois*—were designed and built by the W. Cramp and Sons' Ship and Engine Building Company, Philadelphia, and are all of the same model and plan.

The *Pennsylvania* commenced running between Philadelphia and Liverpool in May, 1873, and was followed by the *Ohio* in August, the *Indiana* in October following, and by the *Illinois* in January, 1874, since which time all have been regularly engaged upon the same route. The vessels are 355 feet long over all,

43 feet moulded breath, and hold moulded 33 feet 6 inches. Their gross tonnage is 3,030 tons.

The engines (see frontispiece) are compound, and surface-condensing, with the crank set at right angles. The cylinders are 57 1-4 inches and 90 1-8 inches in diameter, respectively, and the stroke of the piston is 4 feet. The main slide valves are on the outside of the high and low-pressure cylinders, which are both enclosed in a jacket connecting them together, and forming a receiver. The high-pressure cylinder is also steam-jacketed, but the low pressure cylinder is not. The pistons are 16 3-4 inches deep; the rod for the high-pressure cylinder is 8 inches, and that of the low-pressure 8 1-2 inches in diameter, and both are carried upwards through the cylinder heads. The cross-heads are of wrought iron, with cast-iron slides bolted to their ends. The main slide-valves have double-ports, each is fitted with an independent cut-off-valve on the back, no provision being made for counterbalancing the pressure on the valve faces. The weight of the main valves is counter-blanced by the steam-pressure in a cylinder on the top of the steam-chest. Both main valves are driven by motion of the double-bar link type.

The engines are reversed by direct-acting steam-gear, the reversing cylinder being 20 inches in diameter, with a slide-valve on top, which is

thrown open by hand, and closed by the motion of the piston-rod in any position. A screw is also provided which can be clamped to the piston-rod of the cylinder so as to move the links by hand if there is a want of steam.

Relief-valves are fitted at the end of each cylinder, with gear to use them as starting-valves. The connecting rods are forked at the cross-heads and are fitted with strap ends. The cross-head journals are 10 1-2 inches in diameter 10 1-2 inches long, and the crank-pins are of steel 15 1-2 inches in diameter and 20 inches length of journals. The crank-shafts are built up in two lengths, and are made interchangeable; the main journals are 15 1-2 inches in diameter and 30 inches long, except the forward journal, which is 24 inches long. The cranks are counterbalanced.

The bedplate is made in two parts, and is bolted up to the condenser. This latter is in two pieces, and contains 1,492 tubes, 7-8 inch in diameter and 14 feet long, the surface exposed being thus 4,786 square feet. The water from one circulating pump passes through them three times and from the other twice. The pumps are worked from the main cross-heads through wrought-iron levers, as shown. Each air and circulating-pump is cast separately and bolted to the condenser. A feed and a bilge-pump are bolted to each air-pump. The latter are 26 inches

in diameter, the circulating-pumps are 18 inches in diameter, and the feed and bilge-pumps are each 6 inches. The stroke of all is 26 inches.

Indicator diagrams were taken from the engines of the *Ohio* during her second run, and under the following conditions:

Pressure of steam in boilers	60 lb.
" " receiver	1·5 "
Vacuum in condenser	25·5 in.
Revolutions of engines per minute	60.
Temperature of water in hot well	130°
Steam cut-off at 19 inches in the high-pressure cylinder	
Indicated horse-power in high-pressure cylinder	1237·44
Indicated horse-power in low-pressure cylinder	740·1
Total I. H. P.	1977·54

The running of the *Ohio* during the voyage from Queenstown to breakwater, when the above mentioned diagrams were taken, was as follows:

Date.	Knots Run by Screw.	Knots run by Observation.	Running Time.	
1873.			hours min.	
Oct. 17	246.8	226.0	18 59	
" 18	323.8	280.7	24 23	
" 19	338.5	322.0	24 15	
" 20	335.7	294.0	24 23	
" 21	331.0	No obser.	24 0	15 min. detention.
" 22	341.5	No obser.	24 24	
" 23	336.7	946 in 3 days	23 43	18 min. detention.
" 24	339.5	333.7	24 22	
" 25	343.2	321.0	24 21	
" 26	142.0	140.0	10 30	
	30775	2863.4	9 days, 7 hrs. 20 min.	

The slip of the screw amounted to 212.3 knots, or 6.8 per cent., while the average speed was 12.8 knots. The weather was calm.

That the performance of the engines has been most satisfactory is proved by the great regularity of the passages made by the vessels to which they are fitted, while their workmanship and general finish well deserve praise.

COMPOUND ENGINES OF H. B. M. S.S. "INFLEXIBLE"

BUILT BY JOHN ELDER & CO., OF GLASGOW.

Each screw will be driven by an independent set of compound engines, with three vertical inverted cylinders of the collective power of 4,000 horses, giving an aggregate power of 8,000 horses (indicated) for both sets of engines. The diameter of the high-pressure cylinder is 70 inches, and the diameter of each low-pressure cylinder is 90 inches; the former is placed between the two latter. They are steam-jacketed and are connected together by stay-bolts continued to bulkheads, so as to serve as ramming-chocks. The pistons have a stroke of 4 feet, and the number of revolutions expected is 65 per minute. The piston-rods are double, and are connected by crank cross-heads. They are each 7 inches in diameter, the connecting-rods having a diameter of 9 inches, and a length of 7 feet 6 inches. The valves are of the piston kind. They are worked by link-motions and levers, and are reversed by an ingenious combination of steam and hy-

draulic power. The engines at starting are assisted by auxiliary steam-gear, the valves of which are fitted to the receiver. The steam from the low-pressure cylinders is exhausted into independent surface-condensers, having a total cooling surface of 16,000 square feet. The steam is condensed in the interior of a series of tubes of 3-4 inch external diameter, of which each condenser has no less than 6,650. The condensers are constructed to be worked as common condensers. The circulating-pumps are actuated by separate engines, each having its own feed, bilge, and air-pumps, worked by levers from the cross-heads. The air-pumps are made of gun-metal, with a diameter of 34 inches, and stroke of 2 feet 3 inches, the water being discharged below the armor-deck. With respect to the centrifugal pumps, it may be mentioned that they are judiciously placed at so high a level in the vessel that in the case of leakage occurring by which the ship's bottom may be flooded to as great a depth as 12 feet, they can be worked with perfect freedom. There are also double-acting hand-pumps, each two coupled, feed donkey-engines, each with double-acting pumps 4 inches in diameter; bilge-donkeys, each with double-acting pumps 6 inches in diameter, and fire-engines, with double-acting pumps 8 1-2 inches in diameter. It may be mentioned that the engines which work the cir-

culating-pumps are also made to pump out the bilge, in the event of the ship springing a leak or sustaining damage from being rammed; that the centrifugal pumps are to be sufficiently powerful to perform the same work in case of emergency; and that a Kingston valve is fitted through the bottom, in connection with each fire-pump.

Each cylinder is fitted with an expansion-valve, having a variable cut-off, with an extreme range of from one-sixth to one-half stroke. These valves are cylindrical gridiron-valves, of phosphor-bronze,* 3 feet in diameter, working on cast-iron gridiron seats, and giving a minimum of clearance between the expansion-valve

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* This alloy is now gaining favor for cylinder valve-faces where high-pressure steam is used, and for bearings where heavy pressures are applied. Its component parts consist of copper, tin, and phosphorous, and it is capable of being made tough and malleable, or hard, according to the proportions of the several ingredients. It is rendered so liquid in the molten state by the addition of the phosphorus that it forms very clean castings.

Messrs. Levi & Kingel, of the Val Benoit Nickel works, near Liege, Belgium, have, for a number of years past, been engaged in making experiments for the purpose of improving bronzes of this kind. The results of their experiments are thus summed up by M. Dumas:

"The color, when the proportion of phosphorus exceeds ½ per cent. becomes warm and like that of gold largely mixed with copper. The grain and fracture approximate to those of steel, the elasticity is considerably increased, the absolute resistance under a fixed strain becomes more than doubled, the density is equally increased, and to such a degree that some alloys are with difficulty touched by the file. The metal when cast has great fluidity, and fills the mold perfectly. By varying the dose of phosphorus the particular characteristic of the alloy which is most desired can be varied at will."

In a series of experiments at the Royal Academy of Industry at Berlin,

and main slide. They are worked by an eccentric on the crank-shaft and a slotted lever, and are all connected to a shaft in front of the engines, so that they may be thrown out by a single handle. Each engine is also fitted with a common injection apparatus. The crank-shaft is formed of three pieces, the diameter of the bearings being 17 1-2 inches. The propellers will be about 20 feet in diameter, and will be worked outwards, the thrust being at the after end. The shaft tubes are of wrought iron, supported by struts, while the shafting will be made of Whitworth fluid compressed steel with solid couplings. It will be hollow, the inner diameter being 10 inches and the outer 16 inches. The faces of the high-pressure cylinders are formed of phosphor-bronze 2 inches thick; the liners of the cylinders are also constructed of the Whitworth compressed steel, which possesses properties rendering it not only extremely light, but at the same time much more trustworthy than the ordinary

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a bar of phosphor-bronze, (proportions of components not stated,) under a strain of ten tons, resisted 862,980 bends, while the best gun-metal broke after 102,650 bends.

In Austria the following comparative results have been obtained ·

Absolute Resistance.

	Pounds per square inch.
Phosphor-bronze	81,798
Krupp cast-steel	72,258
Ordnance bronze	31,792

metal used for this and shafting purposes. Each engine will be fitted with a governor, to prevent racing in stormy weather; and in addition to the hand-gear, small auxiliary engines will be erected for turning the main engines.

BOILERS.

The steam is to be furnished by twelve boilers, eight single-ended and four double-ended. They are constructed of the best Low-moor plates, tested to 21 tons lenghtwise and 18 tons crosswise, and the pressure of steam will be 60 pounds per square inch. The four double-ended boilers are 17 feet long, 9 feet 3 inches wide, and 14 feet 3 inches high, with four furnaces in each. Four of the single-ended boilers are 9 feet long, 13 feet 7 inches wide, and 15 feet 6 inches high, with three furnaces each, and the four remaining single-ended boilers are 9 feet long, 11 feet wide, and 13 feet 4 inches high, with two furnaces, each having a separate fire-box. All the boilers are to be clothed with four thickenesses of boiler-felt, and covered with galvanized sheet-iron, and are stayed to prevent their moving by concussion when the ship is engaged in ramming. They are to be supplied with water by four feed-pumps, which are attached to each engine, the pumps being 7 1-2 inches in

diameter, and having a stroke of 2 feet 3 inches. In the event of the feed-pumps receiving injury, the boilers are provided with four small auxiliary engines (one in each boiler-room), and having separate connections with the boilers. The auxiliary engines which are used for washing the decks are also arranged to work the fire-engines in the engine-room. The safety-valves are fitted with springs upon an improved plan. The smoke-pipes, of which there will be two, are 65 feet high from the dead-plate of the lower furnaces. The bunkers, which are placed at the water-line along the unarmored sides of the ship, where the entrance of shot or water cannot injure them, are built to store 1,200 tons of coal, and are so disposed that their contents can be approached from the upper and lower compartments independently of each other.

COMPOUND ENGINES OF H. B. M. S.S. "DREADNAUGHT."

BUILT BY HUMPHREYS AND TENANT, LONDON.

The *Dreadnaught* was engined by Messrs. Humphreys and Tenant. The engines are of the compound type, very similiar to those in the *Alexandra*, constructed by the same firm, and to be described hereafter.

There is an independent set of vertical inverted engines to each of the twin-screws. Each

set consists of three cylinders, the high-pressure exhausting into the two low-pressure cylinders. The diameter of the former is 60 inches ; the diameter of each of the latter is 90 inches, and the stroke of pistons 4 feet 6 inches. All the cylinders are steam-jacketed. The high-pressure jacket is adjusted to the working boiler-pressure of 60 pounds, and those of the low-pressure to 30 pounds. The air-pumps are of composition, and placed fore and aft, immediately under the low-pressure cylinders, from which they are worked. The arrangement is compact and accessible, the condensers forming the midship framing, while the wing framing consists of two wrought-iron columns to each cylinder.

The surface-condensers are of the usual variety employed in the British service. They contain upward of 16,500 square feet of cooling surface, and are fitted to be worked as common jet-condensers in the event of necessity. The condensing water is supplied by two powerful centrifugal pumps, and an extra bilge-suction is provided, so that the air-pumps can receive directly from the bilge in case of an accident by which large quantities of water would enter the ship.

The engine crank-shaft is composed of three pieces, interchangeable ; each piece has a length of 10 feet 7 7-8 inches, and a diameter of 17 3-4 inches. The diameter of the propelling-shafts

is 16 inches, except the lengths in the stern-tubes, which are 18 inches.

The engines are started and reversed by an auxiliary engine having cylinders 6 by 8 inches. The ship is provided with six ventilating-engines, two auxiliary fire-engines, four main fire-engine pumps, steering-engines, turret-turning engines, capstan and ash-hoist engines, besides the engine and hydraulic apparatus for working the guns; in all, there are twenty-nine steam engines on board, and there are one hundred and eighty valves connected with the ventilating-pipes.

The screw-propellers are of Griffith's recent pattern, the diameter of each being 20 feet, with pitches adjustable from 21 to 26 feet,

BOILERS.

The steam for the motive and other engines is supplied by twelve main boilers and one auxiliary boiler. Instead of being arranged in the vessel face to face, as are those in former ships, so that the firemen have fires behind as well as in front of them, they are placed back to back against the middle-line bulkhead of the ship; the firing is thus done at the sides, convenient to the coal bunkers. The boiler-rooms are further divided by athwart-ship bulkheads, whereby four rooms are formed, the forward

ones being 42 feet and the after ones 40 feet in length. The length of the engine-room aft of this is also 40 feet.

The shells of the main boilers are elliptical in shape, 12 feet 2 inches by 11 feet 10 inches, and 14 feet in length, with three furnaces in each boiler; the shells and tube-plates are 3-4 inch thick, and the furnace and back-plates 1-2 inch. The shells are double-riveted, and butt-straps are placed inside and outside the longitudinal seams; the tubes are of composition, and 3 inches in diameter; each furnace is 6 feet 10 inches long, and fitted with 66 wrought-iron grate-bars, 3 1-2 inches deep by 1 1-4 inch broad, and 2 feet 3 inches long.

In addition to the ordinary safety-valve chamber containing a couple of spring safety-valves, each boiler is fitted with a supplementary test-valve placed on the front of the boiler. The stop-valves and safety-valves can be worked from the fire-room floors.

The total heating surface, including that of the auxiliary boiler, is 22,025.5 square feet.

The engines and boilers are entirely surrounded by the coal-bunkers; the bunker immediately forward of the boilers is 22 feet in length, fore and aft, and the one immediately aft of the engines is 8 feet in length; there are consequently 152 feet in the length of the ship by the extreme breadth occupied by the motive

machinery and coal. The bunkers contain 1,200 tons of coal only.

COMPOUND ENGINES OF H. B. M. S.S., "ALEXANDRA."

BUILT BY HUMPHREYS AND TENANT, LONDON.

The *Alexandra* is the first cruising armored broadside ship of the royal navy engined on the compound system. The machinery was designed and constructed by Messrs. Humphreys & Tenant, at their works, Deptford-on-the-Thames.

As in all late armored ships of the royal navy, twin screws are applied to the *Alexandra*. Each screw is driven by an independent set of engines with three vertical inverted cylinders of the collective power of 4,000 horses, giving an aggregate indicated horse-power of 8,000 for both sets of engines. The diameter of the high-pressure cylinder is 70 inches, and the diameter of the low-pressure cylinders each 90 inches. The high-pressure cylinder is in the centre; its faces are made separately, of hard, closed-grained iron, 2 inches thick, and secured to the cylinder with brass countersunk screws. The linings or working-barrels of all the cylinders are made separately, and bolted to the cylinders at one end, and fitted with an expansion joint at the other, with a width of steam space of 1 inch between. The interme-

diate spaces between the high and low-pressure cylinders are also steam-jacketed. The slide-valves are double-ported and fitted with packing-rings on the back, to relieve them of part of the steam-pressure. Chocks are fitted to the cylinders to stay them in the event of the ship being used for ramming. The crank shafts are made in three pieces which are interchangeable. The diameter of the bearings of the crank-pins is 17 1-2 inches, and their lengths equal to the diameters. The crank-shaft brasses are lined with white-metal and so fitted that they can be removed without necessitating the removal of the shaft, and each top brass and cap has a hole large enough to admit a man's hand for the purpose of ascertaining its temperature. The diameter of the propeller shafting is 16 inches, except the stern-shaft through the tube, which is 18 inches, exclusive of the brass casing. The tubes through the stern are of one length, and of gun-metal, and the driving-shafts within them are also cased with gun-metal cast on. The lengths of the lignumvitæ bearings in the tubes are, at the after end, 4 feet 6 inches, at the forward end, 2 feet 3 inches.

The engines are raised considerably above the inner bottom of the ship, with the view to prevent damage to them in case of accident to the ship's bottom. The propeller-shafts are in

consequence inclined toward the stern. The surface-condensers, one to each set of engines, are so fitted as to be worked as common jet-condensers if necessary. They contain an aggregate of 16,500 square feet cooling surface. The tubes are of solid drawn brass, 5-8 inch in diameter, and fitted to be packed at each end in the usual manner practised at present in Great Britain. The water is supplied by means of centrifugal pumps, worked by independent engines. The air-pumps, two to each low-pressure cylinder, are worked directly from the main pistons.

Each set of engines is fitted with two feed pumps and corresponding bilge-pumps; and an auxiliary engine is fitted to each boiler-compartment, capable of working another feed-pump having a set of feed-pipes, feed-cocks, and overflow-valves, separate and distinct from the pipes and apparatus belonging to the main feed-pumps. Two additional auxiliary engines (one to each engine-room) are fitted as fire engines. A double hand-pump to each set of engines is also provided; also a hand-pump to each screw-tunnel, with all necessary attachments, for the purpose of drawing water from the lowest point in the ship. The screw propellers are of the Mangin type, 21 feet in diameter, and work outward.

The boilers are twelve in number, divided by

bulkheads into four several sets. They are placed in the ship back to back against the longitudinal bulkhead. The fronts face the sides of the ship; consequently they are fired from fire-rooms convenient to the coal-bunkers. An additional advantage in this arrangement consists in keeping the sides of the ship clear of boilers, and accessible in the event of torpedoes or rams punching holes through the sides of the ship. The four sets of boilers are arranged to be used separately, in sets, or singly. Each boiler contains three furnaces 40 inches in diameter and 6 feet 6 inches long. The total heating surface is 21,900 square feet, and the pressure of steam to the square inch will be 60 pounds. The smoke and gases are all carried into one chimney. Each boiler is fitted with an internal steam-pipe to obviate the effects of priming. This pipe is of brass, 1-8 inch thick; it extends the whole length of the boiler, and has narrow transverse slits through which the steam must pass. "So as to prevent any catastrophe through the safety-valves getting out of order, each boiler in addition to the ordinary safety-valve box, containing two spring safety-valves, has a supplementary test-valve loaded with a lever and weight and placed on the front of the boilers. There are also two pressure-gauges to each boiler, one being intended to act as a check to

the other, the working gauge being graduated to 80 pounds, and the other to 120 pounds. The stop-valves and safety-valves are all worked from the stoke-hole floors, and the main engine's stop-valves are so arranged that they can be either worked from the engine-room or from the main deck. The whole of the boiler mountings, including the safety-valves and their boxes, are made of gun-metal."

Two cwt. of zinc, in blocks of 12 by 6 by 2 inches, are suspended in each boiler, with the view of preventing corrosion. The furnaces are made in short lengths, riveted together with flanges, having short distance pieces between them. The furnaces, the tube-plates, and fire-boxes are of Lowmoor iron, all the other parts of BB Staffordshire iron. The thickness of the plates is as follows: Tube-plates 3-4 inch; shell 7-8 inch; back 5-8 inch; front, above and below the tube-plates, 5-8 inch; all other parts, 1-2 inch. The shells of the boilers are double riveted, and longitudinal seams have butt-plates inside and outside. The grate-bars are of wrought-iron, 3 1-2 inches deep by 1 1-4 inch wide, and made in three lengths. The fire-rooms are ventilated by means of circular fans, located well up, and driven by small engines.

The complement of engineer-officers is one

chief and ten assistants, and the complement of stokers eighty. In addition to the care and management of the enormous machinery to propel the ship, the engineer-officers have charge of the machinery for steering the ship, for hoisting the anchors, for ventilation, and all the water-tight doors, valves, and cocks in the ship. There are also two pairs of auxiliary engines, immediately aft of the main engines, for revolving the screws when disconnected from the main engine with the ship under sail. These engines work the screws through the intervention of brass bevel-wheels, working into wood cog-wheels, on the couplings of the disconnected shafts. The ship has three masts, is bark-rigged, and is designed as a cruiser. Ventilators are abundantly provided, carrying fresh air throughout the ship; water-pipes are also extended along the decks, with attachments to the steam and hand fire-engines. The estimated speed of the ship is 14 knots as the maximum, and it is believed that 12 1-2 knots under sail may be attained under favorable circumstances.

Since writing the foregoing description of the *Alexandra*, the official trial on the measured mile has been made, when a speed at the rate of 15 1-2 knots per hour was attained, with entirely satisfactory working of the machinery.

The revolutions made by the screws on this trial were 67 per minute, and 8,600 indicated horse-power was developed, which was 600 horse-power above the contract.

It is proper, however, to remark that these heavy engines can never be worked at such high speeds for more than a few minutes at a time.

H. B. M. SLOOP "PELICAN."

ENGINED ON THE PERKINS HIGH-PRESSURE COMPOUND SYSTEM.

The British Admiralty have long been noted for the careful investigation given untried plans of any kind proposed for ships of the royal navy. As a rule, they adopt useful inventions only after such have been sucessfully established in the mercantile marine; a case in point was the caution exercised in the introduction of the compound engine. It must therefore have been unusually strong proof which decided that august board to make the test, on a considerable scale, of a system so far in advance of the present day, and to pass from 70 pounds pressure per square inch as the highest used in boilers of the navy, to 300 pounds pressure per square inch; it was a step beyond anything previously attempted.

The *Pelican* is a composite sloop, of 1,124 tons displacement, building at Devonport. The

steam-machinery for this vessel was designed by the Yorkshire Engine Company, under letters-patent granted Mr. Loftus Perkins, an enterprising American, long established as a manufacturer in London. The novelty of the design and the principles involved are so unlike those which have influenced the construction heretofore of machinery for marine purposes, that the subject has excited no small degree of attention among parties interested in naval and mercantile vessels. The contract provides that the vessel shall on the trials at the measured mile, and on the six-hour runs, develop 900 indicated horse-power, and consume not more than 11.2 pounds of coal per indicated horse-power per hour. The engines have five cylinders of three different diameters, two high-pressure of 16 inches diameter, two medium-pressure of 32 inches diameter, and one low-pressure of 56 inches diameter. One high and one medium-pressure are bolted together, end to end, their pistons are on one casting, and their common piston-rods work through a stuffiing-box in the end of the medium-pressure cylinder. These cylinders are single-acting, the steam being admitted first to the high-pressure, thence on a return stroke to the opposite end of the medium-pressure cylinder, and thence it escapes into a receiver. The other high and medium-pressure cylinders are bolted together in the same man-

ner, and are acted upon by the steam in the same way. The low-pressure cylinder is double-acting, and draws its supply of steam from the receiver into which the medium-pressure cylinders exhaust, and itself exhausts into the condenser. As arranged in the vessel, the cylinders are inclined upward in a small degree toward the ship's sides, but are all on the same side of the the ship. There are three cranks, placed 120° apart, and these are coupled, the after crank to the common piston-rod of one pair of cylinders of high and medium-pressure; the mid-crank to the piston-rod of the low-pressure cylinder, and the forward crank to that of the other pair of high and medium-pressure cylinders. The stroke is two feet, and the revolutions per minute are intended to be about 100. The valves employed throughout are of the piston variety; the advantages claimed for the method of construction in these valves is the almost entire absence of friction, wear, or leakage, combined with a balanced valve. The surface-condenser, also patented by Mr. Perkins, is constructed in such a way as to prevent the possibility of leakage of the tubes when they are correctly fitted.

The tubes are galvanized, and arranged as illustrated by the annexed sketch. The cooling-tubes, which are surrounded by steam, and of which one, C D, is shown, are closed by welding

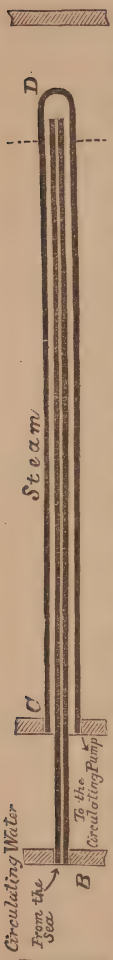

Fig. 45.

up one end, D, and are accurately and permanently screwed into a strong plate at the other end, C. Each has within it a circulating-tube, B, secured to a tube-plate placed at a little distance from the former. The circulating water passes from the sea into and through the internal tube, and returns by the annular space between the two tubes, passing out to the pumps.

The pistons of the steam-cylinders will be made tight by having several rings, or sets of rings, say six, of hard metal; each being separated from the others by what the inventor terms intermediate junk-rings. These rings, of Mr. Perkins's patent metal, are composed of five parts of tin and sixteen parts of copper.

All hot surfaces of the cylinders and pipes are surrounded with a jacket of sheet-iron, packed with vegetable black. Independent air, circulating and feed pumps are to be provided, driven by a separate pair of engines. The boilers contain a nest of built-up tubes, placed horizontally, close to each other, and having the flame and gases passing around and among them.

These tubes are 3 inches in diameter and 3-8 of an inch thick; when put together in the boilers, they are to be proved to 2,500 pounds hydrostatic pressure to the square inch, and to be worked at a pressure of 300 pounds per square inch. There is consequently an enormous margin of safety, and every precaution is to be taken in building the tubes together to insure tightness, and their connections are to be beyond doubt of danger or waste. So also with the engines; they are to be made of the best materials, and to involve the best workmanship. The water-gauges to be employed are made of mica, and to secure a tight joint between the two plates of mica and the two opposite faces of the body of the gauges there is formed a narrow raised edge, against which the mica is firmly pressed by a metal plate applied to its front face.

The first peculiarity of the Perkins system is the extremly high pressure at which he works the steam—in this case from 250 to 300 pounds per square inch; and he claims to have quite overcome all the difficulties hitherto experienced in using steam at sea above ordinary working pressures. A second peculiarity of the system is the absence of internal lubrication with either oil or tallow, thereby avoiding the possibility of corrosion by fatty acids; while, to prevent the wear of cylinders and

slides which is experienced under ordinary circumstances, he uses a metal of his own, whose composition and working are reported as most exceptional. Another peculiarity and important feature of the Perkins system consists in the use, over and over again, of soft fresh water or rain-water. The continually recurrent use of pure water, *not distilled sea-water*, is claimed as the only remedy against the internal corrosion of marine boilers supplied with water from surface-condensers. So much importance is attached to this point, that the committee appointed by the Admiralty to investigate the subject of boiler-corrosion were urgent in their recommendation to test the system, without loss of time, on a scale sufficiently large to arrive at correct conclusions on the subject. Of course this involves the necessity of carrying at sea a supply of fresh water sufficient to make up for all waste accruing during a voyage, and objection has been urged to the system on this account ; but, on the other hand, it is alleged that all joints are to be made mathematically correct and tight, as shown by the boilers and engines now in operation on the system, hence the leakage will be reduced to a minimum. This will be the first attempt to use steam of 300 pounds pressure at sea ; and while an expression of opinion would be premature, it is proper to state that Mr. Perkins has

been entirely successful in his land-engines built on the same system, one of which has been continuously employed at his works for fourteen years, using steam at 500 pounds pressure per square inch. The tubes of this boiler, cut out after thirteen years' service, as inspected by me, were found to be in a remarkable state of preservation, as were also the piston-packing and valve-rings, which had been at work eighteen months without lubrication since the previous examination.

Besides the land-engines manufactured by Mr. Perkins, he has built and kept employed during the last few years, for his own use, a small yacht, the *Emily*, engined on his own system. By invitation of the generous owner I passed a part of two days on board this pretty boat steaming on the river Thames from Westminster Bridge to its mouth, and again to the upper locks, the greater portion of the time running under a boiler-pressure of 500 pounds per square inch. The number of cylinders in this boat is six ; two high-pressure, two intermediate, and two low-pressure. The high and intermediate-pressure cylinders are single acting, the latter exhausting into a chamber from which the low-pressure cylinder is supplied. The steam is expanded 24 times, and the expenditure of fuel is a little above 1 pound of coal per horse-power per hour.

Mr. Perkins has also engined one of the Thames tug-boats on his high-pressure double-compound system. This boat has a length of 69 feet, with a beam of 14 feet 6 inches, and a draught of water of 12 feet. There is in this case a pair of engines working a screw 8 feet 6 inches in diameter, and of 11 feet 6 inches pitch. The cylinders are four in number, with diameters of 15 and 30 inches, and the working pressure is 250 pounds per square inch. It was after the inspection of this boat, the yacht *Emily*, and Mr. Perkins's land-engines that the committee appointed by the Admiralty was induced to recommend the system to be tested on a considerable scale in one of Her Britannic Majesty's vessels.

In consideration of the high indorsement the system of Mr. Perkins has received, and the test to be made by the Admiralty, the sea trials of the *Pelican* will attract unusual interest.

COMPOUND ENGINES OF THE H. M. S. ROVER.

This vessel was built by contract; she has 493 tons less displacement than the *Bacchante* and *Euryalus*. She was launched August 12, 1874, put on the trial-trips in November, 1875, and sent to the West India squadron immediately thereafter. She approaches the size and type of a class of vessels very greatly needed

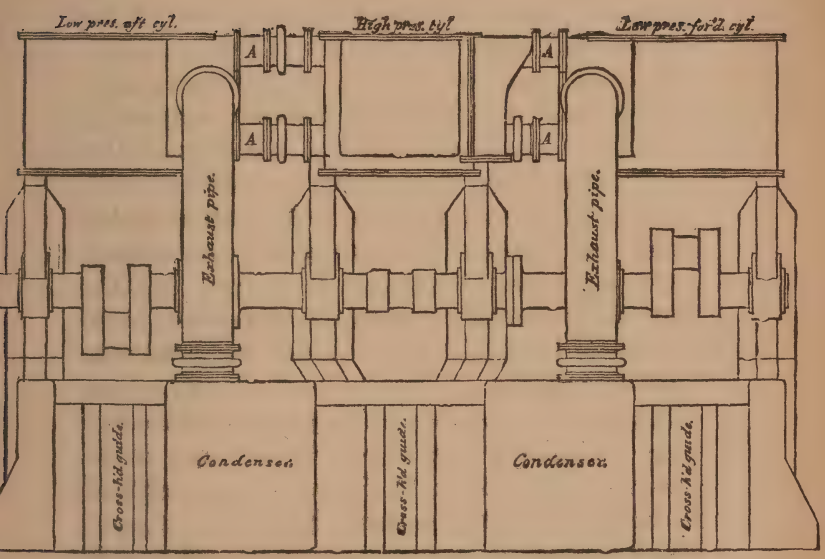

Fig. 46. Compound Engines of H. M. S. "Rover."

in our own navy. The length between perpendiculars is 280 feet; breadth, extreme, 43 feet 6 inches; draught of water forward, 17 feet 2 inches; aft, 23 feet 2 inches; displacement, 3,494 tons.

The contract-price for hull and machinery was $782,460. She was made large enough to be sea-going, to act as a ram, and to be fast; and no ship having structural strength to withstand the engine power necessary to drive her 15 knots per hour, to act as a ram, to have all the requirements necessary for a war-ship, and to keep the sea as a cruiser, is likely to be

made very much smaller until some further advancement is made in engineering.

The engines are the first of their kind completed and used in the British navy, and special interest has been taken in their performance. They are compound and surface-condensing, and belong to the type known as the horizontal return connecting-rod, and have their cross-heads working in slipper guides. According to the contract, they were to indicate 4,750 indicated horse-power at the measured-mile trial.

Fig. 42 shows the main parts of the engines in plan. The diameter of the high-pressure cylinder is 72 inches, equivalent to an area of 4,071.51 square inches of piston. The diameter of each low-pressure cylinder is 88 inches, and the area of piston 6,082.13 square inches. The two low-pressure pistons combined giving an aggregate area of 12,164.26 square inches, the high and low-pressure pistons bear the ratio to each other of 1 to 2.98 in effective area. The high-pressure cylinder, which is fitted with a working barrel made of Sir Joseph Whitworth's patent compressed steel,* is placed between the two low-pressure

* This metal, first introduced by Sir Joseph Whitworth, about twenty years ago, and since used for his ordnance, is now gradually gaining favor for such constructions as demand a material of exceptional strength and toughness, or where a combination of strength and lightness is essential, as in many parts of marine steam engines, especially in cylinder lin-

ones, and each cylinder stands separately and distinctly by itself, securely attached to its own two main frames—these latter, six in all, carrying the crank-shaft. The slide-valve of the high-pressure cylinder is placed on the upper side of it, and lies on its face; the valve-face of the cylinder is cast separately, and bolted to its place, with a view to its ready repair or removal in case of need. The slide-valves of the low-pressure cylinders are placed on the sides of the latter, the valve-faces of these cylinders being also bolted on; and all the slide-valves are fitted with the usual metallic packing-rings on their backs to relieve the pressure. Steam starting-gear, in addition to the ordinary hand-gear, is fitted for facility of handling them, and the easy way in which these large engines can be handled is best told

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ings and valve-faces, where hardness is also necessary to resist abrasion.

Steels, as ordinarily cast by pouring into ingot-molds, are found to be porous and comparatively heterogeneous in texture, and brittle, in consequence of gas and air-holes. Whitworth adopted the simple but effective expedient of subjecting the ingot or casting, while still molten, to the tremendous pressure of a heavy hydraulic press while solidifying; by this means the pores and bubble-holes are effectually closed, and the compressed steel is given a strength and homogeneity unequaled by any other known metal. Although a simple expedient, it has required a considerable amount of experiment, ingenuity, and cost to produce this compressed steel with uniform success; this was, however, accomplished, and the material is now used in the British navy, in France, and in Austria.

The inventor has stated that by a careful selection and treatment of metals, a steel can be produced capable of resisting a tensible stress of 45 tons per square inch of section, and of elongating 25 per cent. before breaking.

First cost is the only objection raised against its general use.

by describing the results obtained. While running full speed ahead, they were stopped in nine seconds, went astern at full speed in six seconds more, and were reversed from that position to full speed ahead again in eight seconds. The casing of the high-pressure slide-valve, to which the expansion-valve casing is attached, is connected with the low-pressure slide-valve casings by four copper pipes, A, A, A, A, which are fitted as shown, and through which the steam passes after leaving the high-pressure cylinder. These pipes and the passages connected with them form the only steam reservoirs between the cylinders. The surface-condensers are on Hall's system, the steam passing through the tubes; they stand on the side of the connecting-shaft, opposite to the cylinders, and each condenser is connected with its own low-pressure cylinder by an eduction pipe, through which the steam passes on leaving the latter. The condensers have a total number of 7,224 brass tubes, tinned inside and outside, with a total cooling surface of 9,500 square feet. The tubes are fitted in the tube-plates with screwed glands and stuffing-boxes, and the condensers are so arranged that they may be worked as common condensers, if required. The air-pumps, double-acting, are two in number, 23 inches in diameter, with a stroke of 4 feet, and

the circulating water is driven through the condensers by two centrifugal pumps worked by an independent pair of small engines, and the main receiving-pipes to these pumps are fitted with branches leading into the bilges of the vessel, so that the pumps may become large bilge-pumps in the event of any leak arising in the vessel. There is the usual arrangement of feed and bilge pumps fitted on the main engines, two of each ; they are of gun metal, and are 5 inches in diameter, with a stroke of 4 teet. In addition to these pumps there are two feed auxiliaries, a bilge auxiliary, hand-pump, and fire-engine, all fitted in accordance with the Admiralty specification.

The length of the stroke of the main engines is 4 feet, and the length of the connecting-rod is twice the length of the stroke. The diameter of the connecting-shafts is 18 inches, and of the crank-pins 20 inches. The shaft is made in three pieces, having couplings forged on the ends, by which they are bolted securely together. The diameter of the line-shafting is 16 1-2 inches, and that of the stern-shaft is 18 1-2 inches, the latter running in the usual lignum-vitæ bearings fitted in the stern-tube. The screw-propeller is of gun-metal, is on the Hirsch principle, has a diameter of 21 feet, and is driven by an ordinary cheese-coupling keyed on the stern-shaft, and is fitted to lift in a banjo-frame

by means of sheer legs and tackles on deck.

BOILERS.

The boilers, which are ten in number, stand athwartships in two groups. Each group of four and six, respectively, has its own separate chimney, fitted on the telescopic principle, and the boilers carry a working pressure of 70 pounds to the square inch. They are about 11 feet 10 inches in diameter, 9 feet 6 inches long, fitted with brass tubes 3 inches in outside diameter, and with wrought-iron stay-tubes. Each boiler has two furnaces 3 feet 10 inches in diameter and 6 feet 8 inches long. The total heating-surface of the boilers is 12,700 square feet, and the grate-bar surface is 510 square feet.

Among other fittings of the engines it may be mentioned that both low-pressure cylinders have separate starting-valves; a double-beat regulator-valve is placed in the main steam-pipe close to the expansion valve, and besides this a steam separator. There is also a throttle-valve to be used with a Silver's governor. The high-pressure piston is provided with a 20 inch trunk at the back, which is enclosed in a casing bolted upon the cylinder-cover, and works always upon an adjustable composition block; the latter thus takes the principal weight of the piston, by which means it is hoped that excessive wear of the cylinder may be prevented. This adjustable block is regulated by

set-screws, and although at the time when made it was thought to be an improvement, it has since been found to be a disadvantage, because there is no means of ascertaining just how much to raise or lower the piston. The starting and reversing gear referred to is simply a vertical steam-cylinder with the necessary valve-gear; the lower end of its piston-rod is connected by a link with the reversing gear, the upper end of the same rod is formed as a very coarsely-pitched screw; this is so proportioned that it does not move of itself when steam is turned on, but is then so far balanced that scarcely an effort is required at the hand-wheels (of which two are provided and connected with the piston-rod by bevel-gearing), in order to move the reversing-links in either direction.

The following results were obtained in November on the measured-mile trial: The mean speed on the six full-power runs was then 14.533 knots, the mean revolutions being 68.51; steam, 68 pounds to 70 pounds; vacuum, 27 1-2 inches. The mean indicated horse-power on these runs was 2,476.6 in the high-pressure cylinder, 1,343.2 in the forward low-pressure cylinder, and 1,143.7 in the after low-pressure cylinder; the total being thus 4,963.5 indicated horse-power. The mean speed on the four half-power runs was 11.714 knots with

54.26 revolutions, 66 pounds of steam, and 28 inches of vacuum. The indicated horse-power was 1,240 in the high-pressure cylinder, 580.6 in the forward low-pressure cylinder, and 501.7 in the after low-pressure cylinder, the total being 2,322.3. The propeller was set at a mean pitch of 24 feet 11 inches.

As previously stated, the engines of the *Rover* are the first of the kind put on trial in the royal navy. The most marked feature about them is the use of two low-pressure cylinders instead of one. The diameter of one cylinder equal in area to the two low-pressure cylinders of the *Rover*, would be nearly 124 1-2 inches. Cylinders of about this size have been used in Her Britannic Majesty's navy, working with pressures greater than those at which the low-pressure cylinder of a compound engine works, and they have been used in the merchant-service in compound engines; but the experience with these large cylinders has been very unsatisfactory, consequent upon the number that have been cracked by unequal expansion and contraction in these large castings, besides which the inconveniences of handling and working with such large and heavy parts in the confined space of an engine-room are very great. For these reasons the low-pressure cylinders have been kept within reasonable limits in all recently-

designed engines for the naval service.

The engines and boilers of the *Euryalus* are similar to those of the *Rover* except that the high-pressure cylinder has a diameter 2 inches greater than that of the *Rover*, the low-pressures are correspondingly increased in diameter, and also the working parts. The power of the boilers is also increased by an addition of one furnace in each, thus making 30 furnaces in the ten boilers, each having a diameter of 3 1-2 feet and a 6 foot length of grate.

During the time these and the several other sets of three cylinder engines have been building, the subject of the position in which the cranks should be set relatively to each other has received considerable attention and discussion. At the fifteenth session of the Institution of Naval Architects, Mr. G. B. Rennie, a distingished mechanical engineer and marine engine builder, read a paper on the subject (to be noticed directly), and at the last session of the same institution, Mr. John R. Ravenhill, also well known as a mechanical engineer, made the following statement :

"In the month of March, 1874, a paper was read by Mr. G. B. Rennie, on engines at that time under course of construction by his firm for her Majesty's steamships *Boadicea* and *Bacchante*, in which he brought under our notice a series of diagrams showing the theoretical force exerted

by the three cylinders at all parts of the path of the crank-pin's centres, in four different ways of setting the relative angles of the cranks, which he described as follows: A.—With equal angles of 120° with each other. B.—The two low-pressure cranks with 90° between them, and 135° between these and the high-pressure crank. C.—The low-pressure cranks with the same angle between them, but at angles of 150° and 120° with the other one. D.—The low-pressure cranks placed opposite to each other, and at right angles to the high-pressure crank. And he proceeded to give his reasons for concluding to adopt the position described in D. for the angles of the cranks of the two above-named ships. (See A. B. C. D., Fig. 47.) In the discussion that followed, I stated that in three-cylinder compound engines then making by my late firm for the *Rover*, I had adopted the plan of placing the cranks at equal angles of 120° with each other and promised to furnish the institution with the practical result obtained. Recent experience has demonstrated most clearly that we have closely approached, if we have not actually reached, the point at which the crank-pins of large high-speed engines will work satisfactorily in consequence of the very limited amount of bearing surface that of necessity can be alloted to them; and unless phosphor-bronze should come to

the assistance of the marine-engineers, as white-metal and lignumvitæ did in days gone by, it may be necessary to reduce the load on the high-pressure crank-pins. Rather than depart from the angle of 120° for my cranks, I would alter the multiple of my cylinders, for with the three cranks set at equal angles to each other you possess the great practical advantage of being able to work on with any two cylinders out of the three, under many circumstances, in the event of temporary derangement with the third, an advantage that might prove to be the salvation of a ship and her crew on a lee shore, or in the time of war."

It will be seen that the cranks of the engines of the *Rover* are set as represented by the position at A. The cranks of the engines of the *Boadicea* and the *Bacchante* are set according to the positions represented at D. In the armored ships *Alexandra* and *Dreadnaught*, the position adopted for the engine-cranks is that of B.

On the following page will be found the paper read by Mr. Rennie, at the fifteenth session of the Institution of Naval Architects, 27th of March, 1874. The diagrams produced by him, and referred to above, will be found at page 275.

THREE-THROW CRANK ENGINES OF THE COMPOUND SYSTEM—H. M. S. S. "BOADICEA" AND "BACCHANTE."

BY G. B. RENNIE, ESQ., MEMBER OF COUNCIL.

Since I had the honor of reading a paper before you on the subject of compound engines of her Majesty's ship *Briton*, in 1871, the system of engine adopted in the navy has been almost entirely compound, even to the largest size. The engines for the ships *Thetis*, *Encounter*, and *Amethyst* closely followed those of the *Briton*, of similar size and construction, besides others of the same size, and many smaller, all of these were made with one high-pressure and one low-pressure cylinder; but when a much larger power than that developed in the *Briton* was required, it was considered advisable by Mr. Wright, chief engineer of the Admirality, to have two low-pressure cylinders and one high-pressure cylinder, on account of the risk involved in making good castings of the size of cylinders that would be required if made with one low-pressure cylinder, especially as casualities had taken place in some of the larger cylinders in her majesty's ships.

Last year my firm entered into a contract for two sets of compound engines, each 5,250 horse-power, to be fitted on board her majesty's ships *Boadicea* and *Bacchante;* each set of

engines has three cylinders, one high-pressure of 73 inches diameter, and two low-pressure of 93 inches diameter, the stroke being 4 feet.

Wishing to ascertain the most advantageous angles to place the cranks in relation to each other, so as to develop the required power with the greatest regularity of motion, with the least strain on the shaft, I had some carefully-made diagrams constructed, taking into account the cut-off to which the valves were made to [work], as well as making allowance for the capacity of the ports, passages, etc., between one cylinder and the other at each successive point of the travel of the pistons. The steam being cut off at *half-stroke* in the high-pressure cylinder by a separate expansion-valve, and at three-fifths of the stroke in the two low-pressure cylinders: the initial pressure being 82 pounds, and the back-pressure, from imperfect vacuum, at 4 pounds. It was impossible to make allowance for the "wire-drawing" of the steam through the ports, pipes, etc., with any degree of accuracy; this, therefore, was not taken into account, so that the total horse-power indicated on the diagrams is in excess of that which would be actually realized in practice; but as each case is relatively the same in this respect, it would not affect the general comparison.

The diagrams as shown in fig. 47. are made for four different positions of cranks.

A.—With equal angles of 120° with each other.

B.—The two low-pressure cranks, with 90° between them, and 135° between these and the high-pressure crank.

C.—The low-pressure cranks, with the same angle between them, but at angles of 150° and 120° with the other one.

D.—The low-pressure cranks placed opposite to each other, and at right angles to the high-pressure crank.

Having thus ascertained the pressures at different points, in each case, when the cranks were placed at the above-named angles, the diagrams of the tangential forces were constructed, taking into account the length of the connecting-rod, to be four times that of the crank.

These diagrams show the force exerted by the three cylinders at all parts of the path of the crank-pin centre; and the greater regularity of the curve, and the nearest approach to a straight line, the more uniform the rotation of the shaft and screw-propeller.

It is seen clearly by the diagrams that the most uniform motion is derived by placing the cranks at right angles, as in D; and the next best position is where the angles are equal. (A.)

The more uniform motion also gives the least maximum strain on the shaft, and thus allow-

ing for the same margin of safety in each case. And, supposing in one case the diameter of the shaft to be 18 inches, in the other it would have to be 19 1-2 inches diameter.

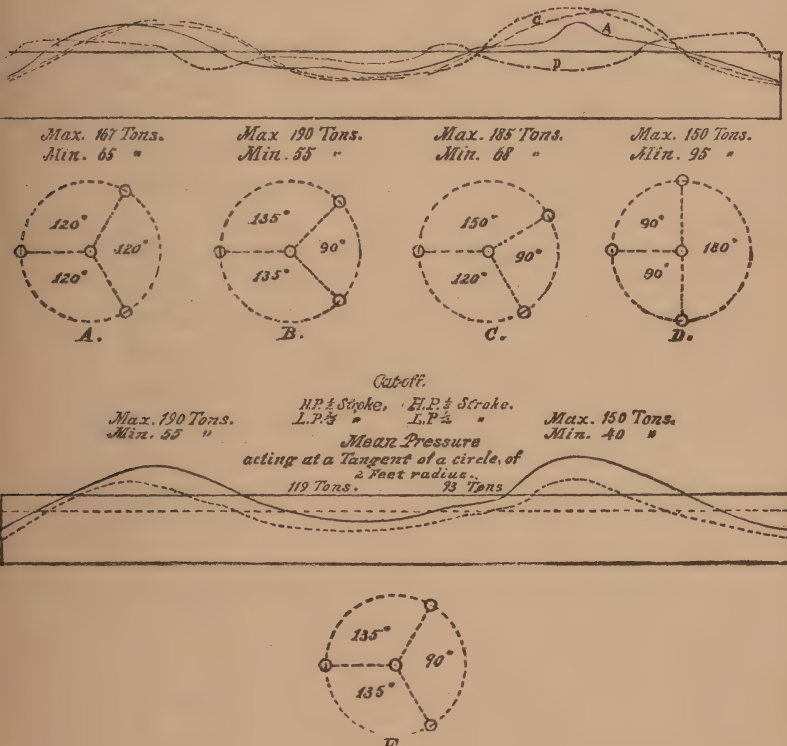


Fig. 47.

As regards the better propelling-machine, I can fancy there can be little doubt among

naval engineers that a steady, continuous pressure will be a far better propelling-machine than one subject to a series of jumps and variations of strain during the rotation of the propeller.

In order to ascertain the effect of an earlier cut-off than half-stroke, I had a further diagram (E. fig. 47.) made, supposing the steam cut off at one-third in the small, and one-half in the large cylinders, but this does not appear to affect the irregularity of the motion, but merely shows a gradual depression throughout the circle. How far a greater cut-off in the low-pressure cylinders affects the curves I have not yet gone into, the engines in question not being fitted with separate expansion-valves on the low-pressure cylinders.

From these examples, it seems to me that in compound engines—whether with two or three cylinders—the best position to place the cranks, both for uniformity of motion as well as strain on the shaft, is where the low-pressure cylinder cranks are placed at right angles to the crank of the high-pressure cylinder.

H. B. M. S. S. NELSON.

The machinery of the *Nelson* was designed and constructed under the direction of Mr. Kirk, the manager of the engineering works of Messrs. Elder & Co. The ships are fitted with twin

screws, each to be driven by an independent pair of compound engines, with vertical inverted cylinders, of the collective power of 3,000 horses, giving an aggregate power of 6,000 indicated horse-power for both pairs of engines. The diameter of the high-pressure cylinder is 60 inches, and the diameter of the low-pressure cylinder is 104 inches. The length of the stroke is 3 feet 6 inches, and the number of revolutions to be obtained on the trial is 75 per minute. These engines are constructed entirely of wrought-iron and brass, except the cylinders, cylinder covers, steam and expansion-valves. The two pairs of engines are tied together by wrought-iron braces, and are to be fixed in the ship directly opposite each other. The central longitudinal bulkhead of the ship, however, divides the two pairs, and all the pipes are arranged so that, in the event of collision or other casualty to the bottom of the vessel, either pair can be worked separately. The crank-shafts are in two parts, interchangeable, 16 1-2 inches in diameter in the bearings, with an aggregate length of bearing of 9 feet 6 inches. The propeller-shafts are hollow, made of Whitworth's compressed steel. The screw-propellers are to be 18 feet in diameter, to work outward, and to be of the Mangin type, *i. e.*, two two-bladed screws on each hub, separated from each other.

The boilers are ten in number, with three

furnaces in each, set back to back against the longitudinal bulkhead, with the fronts toward the sides of the ship. They are oval in shape, 12 feet 6 inches wide, by 14 feet 6 inches high, and 9 feet 6 inches long, and are divided by transverse water-tight bulkheads into four separate fire or boiler-rooms. The furnaces are made in short lengths, riveted together with flanges having distance-pieces between them. The pressure of steam is to be 60 pounds per square inch. All the necessary pumps and equipments described for other vessels are here provided.

H. B. M. S. S. "NORTHAMPTON."

The machinery for the *Northampton* was designed and constructed by Messrs. John Penn & Son, of Greenwich. The engines of this ship are of Penn's new type, three-cylinder vertical inverted, the first design of which was made in 1875 for the Italian frigate *Cristoforo Colombo*, built at Venice. The three cylinders are of equal diameter, 54 inches, with a stroke of 39 inches. The cranks are set at equal angles, and the shafts are interchangeable. When the ship is to be driven at full speed, the engines are to be worked as simple expansive engines, cutting off the steam long or short, as desired; but under all ordinary conditions of steaming they are intended to be

worked on the compound system, taking the steam first in the centre cylinder and expanding it in the two outside cylinders, valves and connections being provided to effect the change from one system to the other when desired. The only difference between the general design of these engines and the set built for the Italian government is, that in the former the cylinders are separate from each other and tied together by wrought-iron braces, while in the latter they are united by castings. The power to be developed by the engines of the *Northampton* is to be the same as provided for the *Nelson*, and the boilers are almost identical, ten in number, of the elliptical type, with three furnaces in each, and to carry a pressure of 60 pounds per square inch.

The ends of the ship are provided for coal-tanks.

ENGINES OF H. B. M. S.S. "DEVASTATION."

The *Devastation* is propelled by twin screws, each driven by an independent pair of engines. These engines, which were constructed by Messrs. John Penn & Sons, of Greenwich, are of that firm's direct-acting trunk type, contracted for prior to the adoption of compound engines, and they have cylinders 88 inches in diameter, and trunks 36 1-2 inches in diameter; the trunks reducing the effective area of the pistons to that

due to a diameter of 80 inches. The cylinders are steam-jacketed, both at sides and ends, and the stroke of pistons is 3 feet 3 inches. The engines are fitted with expansion gear, which enables the steam to be cut off at any required part of the stroke. The main slide-valves are double-ported, and fitted with an equilibrium ring. The expansion-valves are of the grid-iron form, with a variable stroke and cut-off. The admission of steam to the engines is regulated by equilibrium valves, which are worked by screws and suitable gearing, led away to the starting platform. To insure ready handling of the engines, small auxiliary slide-valves are fitted to each cylinder. Each pair of engines is fitted with a surface-condenser containing 5,432 3-4 inch tubes, 6 feet 3 1-2 inches long, the condensing surface for each pair of engines being thus 6,710 square feet. The tubes are packed with screwed glands and tape packing. The air-pumps and the circulating-pumps are double-acting, and are worked direct from the pistons. The condensing water is drawn through the tubes and the steam admitted to the outside. The crank-shafts are in two pieces, with solid coupling forged on. The turning-gear consists of a worm-wheel and worm, worked by hand by means of a long ratchet lever. The disconnecting coupling is fitted with four steel pins, which can be drawn

out of gear by means of screws and ratchet spanners. The thrust of the propellers is taken by a bearing fitted with ten movable collars. The screw propellers are 17 feet 6 inches in diameter, and have 19 feet 6 inches pitch, and are so fitted that the pitch can be varied from 17 feet to 22 feet. The number of blades to each is four, and the propellers are formed on the Griffiths principle. The boilers are eight

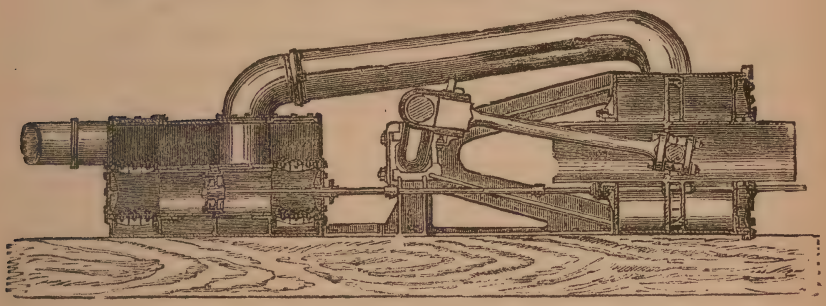


Fig. 48.

ENGINES OF H. B. M. S. S. DEVASTATION.

in number, of the old kind, containing thirty-two furnaces, the four boilers in the forward fire-room having four furnaces each, while of the four boilers in the after fire-room two have three, and two have five furnaces each. The length of bars is 6 feet 6 inches, and the width of furnaces 3 feet 2 inches, the total fire-grate area being thus 742 square feet. The boilers contain in all 2,592 tubes 3 1-2 inches in dia-

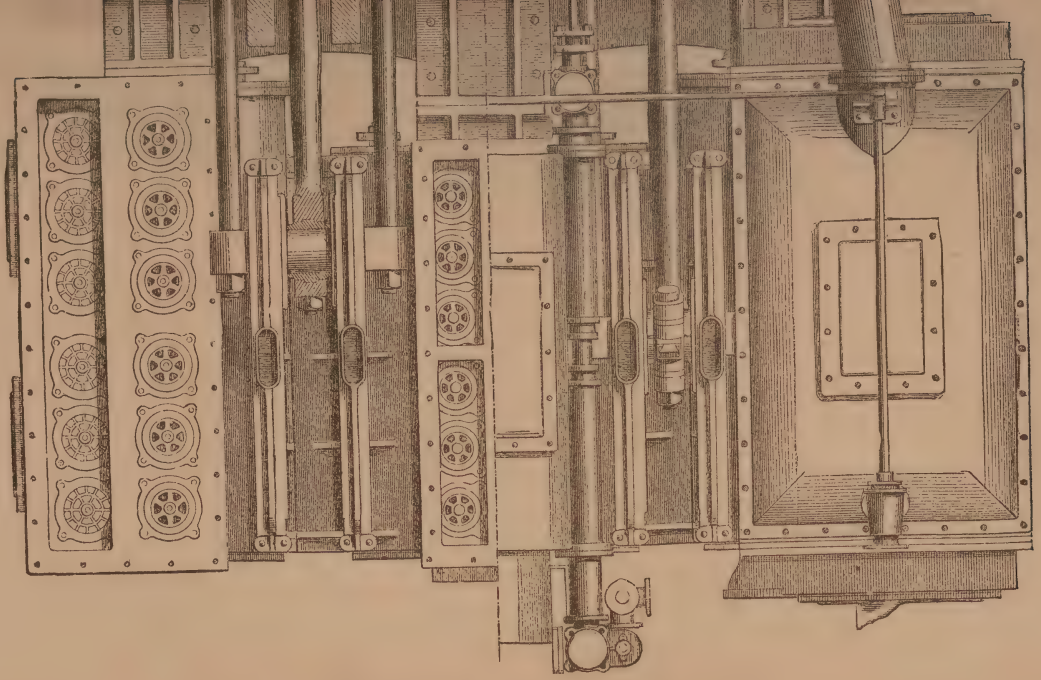
meter and 6 feet long. The working pressure of steam is 30 pounds per square inch. The total heating surface is 17,806 square feet. A superheater is fixed in each chimney, of which there are two, the total superheating surface exposed being 1,866 square feet. The chimneys are telescopic, and are fitted with hoisting gear and shell-proof gratings at the bottom. The length in the ship occupied by the engines is 32 feet, and that by the boilers 89 feet, this latter length being divided into two equal compartments, separated from the engines and each other by water-tight bulkheads.

ENGINES OF H. B. M. S.S. "RALEIGH."

These engines, (fig. 49.) constructed by Humphreys, Tenant & Co., are of the horizontal, direct-acting, return-connecting-rod type, and intended to indicate 6,000 horse-power. A few of their dimensions are as follows:

Number of cylinders	2
Diameter of cylinders	8 feet 4 inches.
Stroke	4 feet 6 inches.
Diameter of piston-rods	7 inches.
Travel of slide-valves, (vertical, double-ported)	10¼ inches.
Depth of valve	5 feet 10 inches.
Width of valve	5 feet 1½ inches.
Depth of ports	5 feet 2 7-16 inches.
Depth of bars in extreme ports, 2 in each	2 inches.
Depth of bars in other ports, 2 in each	1 inch.

The expansion-valves are horizontal, and of the gridiron type, placed above the slide-casing, and worked from rocking-shafts by means of eccentrics on the main shaft. The cut-off ranges from 3 1-2 inches of the stroke onward,



ENGINES OF H. B. M. S.S. "RALEIGH," (fig. 40, p. 282.)

and is varied by moving the end of the eccentric-rod along a quadrant arm on the rocking-shaft. There is one surface-condenser to each cylinder. The air-pumps are 25 1-2 inches in diameter, double-acting, and worked direct from the pistons. The circulating-pumps are centrifugal, and driven by separate engines with 12-inch cylinders, having 12 inches stroke, exhausting into the condensers; the water is forced through the condensers outside the tubes. The condenser-tubes are vertical, and there are 6,740 in each condenser; their dimensions are as follows:

Diameter inside	⅝ inch.
Diameter outside	⅝ inch.
Length between tube-plates	6 feet 6½ inches.
Cooling surface	12,000 square feet.

The starting-gear can be worked by hand or steam. A Silver's governor is fitted. The propeller is by Hirsch, two-bladed, has 26 feet 8 inches pitch, and is fitted for being raised when the ship is under sail alone. The number of boilers is nine; but two of them are small and intended for auxiliary purposes; these are together equal to one of the large ones. The chief data relative to the boilers are as follows:

Number of chimneys	2
Number of furnaces	32
Length of fire-grate	6 feet 10 inches.
Breadth	3 feet 3½ inches.
Area of fire-grate	720 square feet.
Number of tubes	2,880
Length between tube-plates	6 feet 4 inches.
Diameter of tubes outside	3 inches.
Tube-heating surface	14,300 square feet.
Number of superheaters, (steam passing through the tubes)	2

Number of tubes	248
Diameter of tubes, inside	2 inches.
Length of tubes	9 feet.
Superheating-tube surface	1,170 square feet.

The boilers are of the ordinary box kind, and carry 30 pounds pressure on the square inch. The dimensions quoted above give the following relative areas per indicated horse-power:

	Square feet.
Grate surface	.117
Tube-heating surface	2.32
Superheating-tube surface	.19
Condenser-tube cooling surface	1.95

Trials of Her Britannic Majesty's ship "Raleigh."

Date of trial	April 1, 1874			September 2.	September 2.
Kind of trial	Measured mile			6 hours	Meas'd mile.
Where tried	Maplin Sands			Off Portsmouth	Stokes Bay.
Draught:					
Forward	19 feet 6 inches			21 ft. 10 in	21 ft. 11 in.
Aft	23 feet 6 inches			25 ft. 2 in	24 ft. 10 in.
Mean	21 feet 6 inches			23 ft. 6 in	23 ft. 4½ in.
Ship by the stern	4 feet			3 ft. 4 in	2 ft. 11 in.
Screw:					
Diameter	21 feet			21 ft. 1 in	21 ft. 1 in.
Length, great'st	3 feet 2½ inches			3 ft. 3¾ in	3 ft. 3¾ in.
Upper edge immersed	2 feet 10 inches			2 ft. 5½ in	2 ft. 1½ in.
Force of wind	4 to 5			4 to 5	3.
State of sea	Smooth			Moderate	Smooth.
Steam-pres. and temperature:					
Boilers	32.7 pounds.	Half power.	29.1 pounds	27.4 pounds	28.3 pounds.
Superheaters	Mean, 310°		370°	Mean, 325°	Mean, 320°
Engines	31.2 lbs. 274°		27.6 lbs. 282°	25.9 lbs. 289°	26. 8 lbs. 281°
Vacuum:					
Forward	27.6 in.		27.4 inches	27.0 inches	26.8 inches.
Aft	26.9 in.		26.4 inches	26.5 inches	26.8 inches.
Rev. per minute	73.9		58.5	68.8	69.6
Indicated mean pressure	19.8		13.8	19.1	19.2
Indicated horse-power	6157		3413	5541	5639
Speed of vessel	15.503		13.455	15.139, cal'ed	15.320
Rev. per knot	286.0		260.8	272.5, cal'ed	272.5
Slip, per cent	20.28		12.6	16.35, cal'ed.	16.35
Temperatures:	Full power.				
Deck	56 degrees			65°	64°
Engine-room	77 degrees			87°	83°
Stoke-hole, aft	105 degrees			118°	108°
Stoke-hole, fore	118 degrees			110°	92°
Kind of coal used on trial	Nixon's Navigation			Nixon's Navigation.	Nixon's Navigation

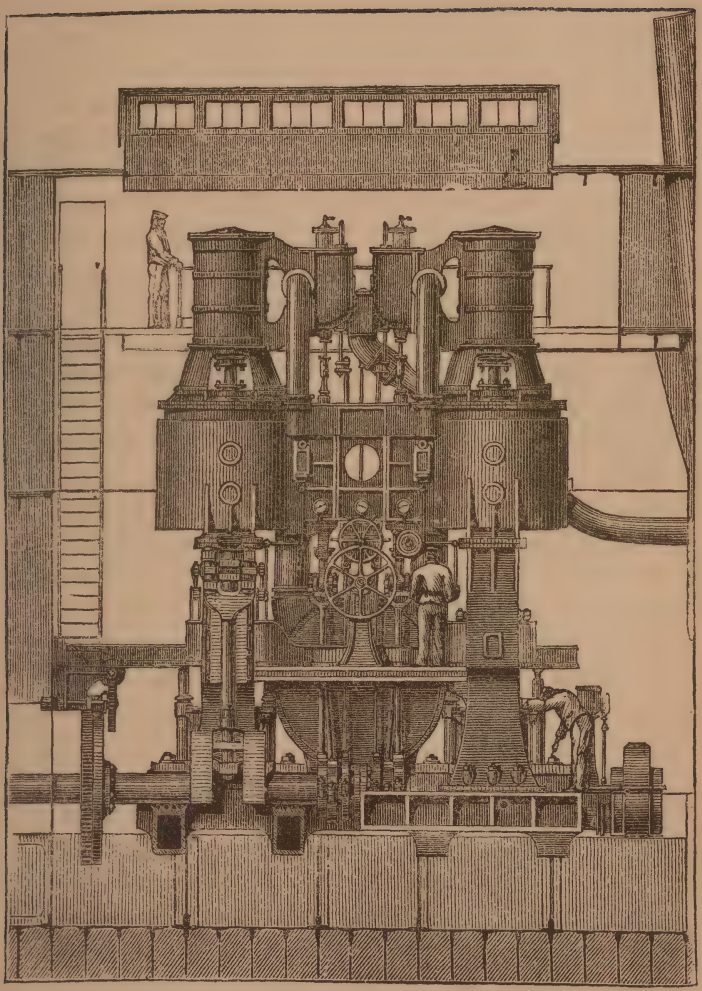
ENGINES OF H. B. M. S.S. "SHANNON."

The ship is to be propelled by a single screw. The machinery was constructed by Messrs. Laird Bros. The engines are of the compound, horizontal, return-connecting-rod type, with four cylinders—two high and two low-pressure —bolted together similarly to the White Star type, if laid horizontally. The diameter of the high-pressure cylinder is 44 inches; the diameter of the low-pressure cylinders is 85 inches, and the stroke of pistons is 4 feet. The condensers are of the ordinary surface variety used in the British navy. The diameter of the air-pumps is 22 1-2 inches, and the stroke 4 feet. The diameter of the crank-shaft is 17 1-2 inches. The screw-propellor is of the common Griffith type, two-bladed, and lifting; its diameter is 19 feet 6 inches, and its pitch varies from 18 to 22 feet, according to the position in which the blades may be set. The boilers, cylindrical in form, are eight in number, each 12 feet long, and each boiler contains two furnaces 3 feet 8 inches in diameter by 6 feet in length. They are placed in the vessel back to back, against a longitudinal bulkhead, and as a consequence are divided into two sets, with the fire-rooms facing the side coal-bunkers; in this position they are conveniently fired. A transverse bulkhead separates the boilers from the engines;

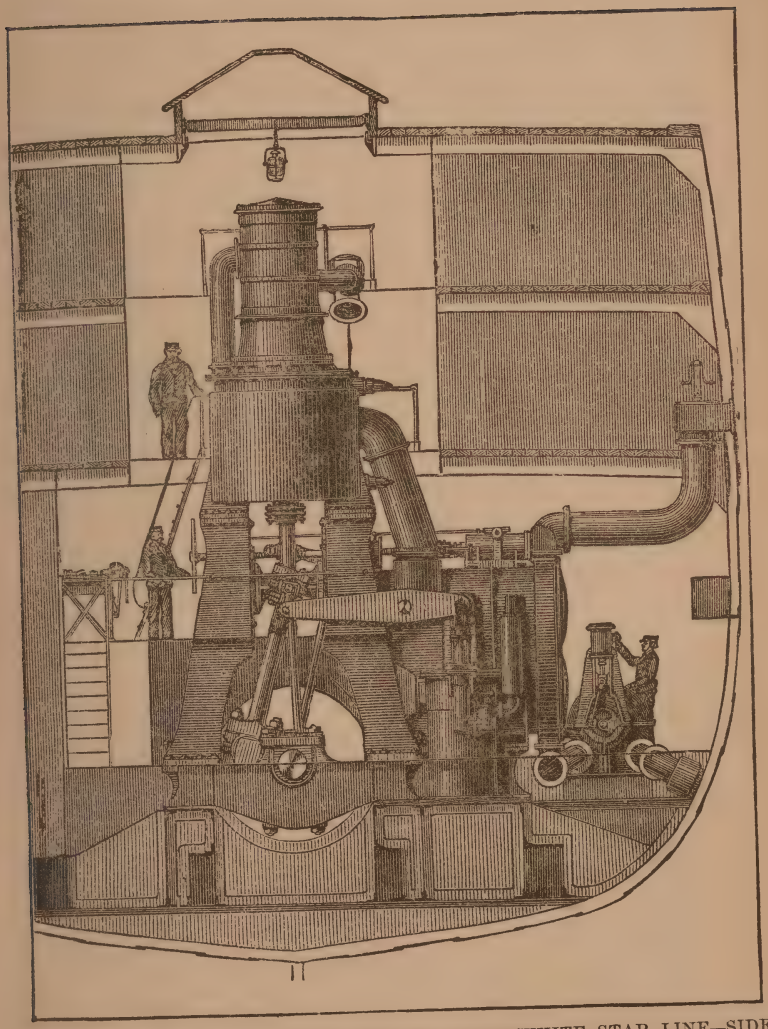
also, a transverse bulkhead forward separates them from the hold ; hence the central position of the boilers in the vessels, the division into the two fire-rooms, and protection by water tight bulkheads, gives all the security to them possible in the event of damage to the hull by rams or torpedoes. The entire length of the boiler space in the vessel is 56 feet, and the width, including the two fire rooms, is about 40 feet. The space occupied by the engines in the length of the vessel is 36 feet. The pressure of steam to be carried in the boilers is 70 pounds per square inch. The maximum number of revolutions of the engines is to be 70 per miuute. At this speed of pistons, 560 feet, the indicated horse-power is estimated at 3,500 and the speed of the ship at 13 knots per hour. The engines are designed to work the steam expansively, from 12 to 20 times as desired. The coal-bunker capacity is only 500 tons ; it is therefore evident that steaming will be the exception and sailing the rule in the *Shannon*.

WEIGHTS OF MACHINERY.

Engines, appendages, and spear gear, with water in condensers, 266 tons ; boilers, including everything between boiler-room bulkheads, also, water in boilers, 310 tons ; propeller, shafts, etc., 161 tons ; total, 627 tons. Total cost of machinery, $244,430.



FOUR CYLINDER COMPOUND ENGINES OF THE WHITE STAR LINE—FRONT ELEVATION, (fig. 50, p. 287.)



FOUR CYLINDER COMPOUND ENGINES OF THE WHITE STAR LINE—SIDE ELEVATION, (fig 51, p. 288.)

FOUR-CYLINDER COMPOUND MARINE ENGINES.

These engines were designed by Messrs. Maudslay, Sons, and Field, and fitted in the vessels of the White Star line of mail-steamers which make the voyage between Liverpool and New York. Similar engines have also been fitted in other vessels. They work to about 5,000 horse-power, and exhibit a remarkable economy in the consumption of fuel; presenting, in fact, an admirable practical illustration of the excellence of the system now adopted in powerful steamships.

The writer is enabled to present two external views of the engines in question, as well as a section through the cylinders and valves, which latter will give the student a complete insight into the method of distributing the steam.

Fig. 50 is a front elevation of the engines; fig. 51 is a side elevation, showing also a section of the vessel; and fig. 52 is a section through the cylinders. But inasmuch as a section perpendicular to the screw-shaft does not take in the valves and steam passages, the drawing in fig. 52 is altered hypothetically, and the valves are supposed to be brought round into the plane of section. In this way one diagram suffices for exhibiting both the working of the valves and the connection of the pistons with the screw-shaft.

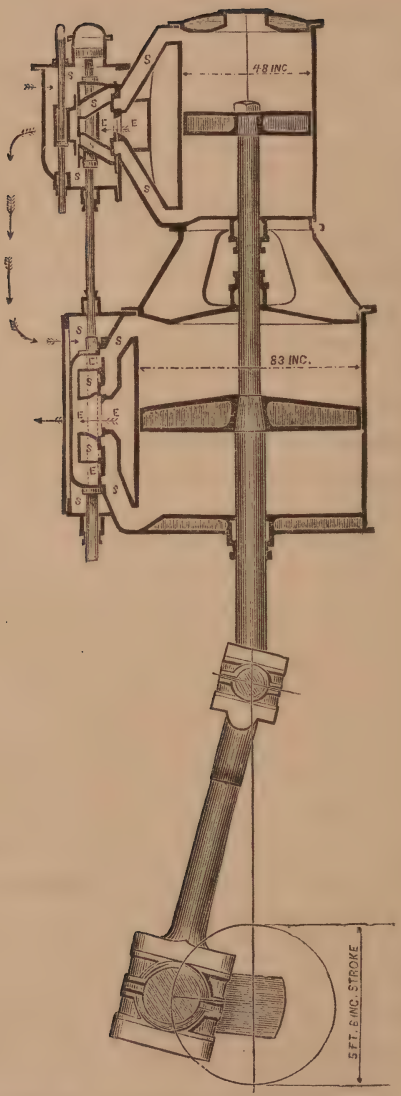


Fig. 52. Section through cylinders.

To begin with the smaller, or high-pressure cylinder, which is 48 inches in diameter, with a stroke of 5 feet. Steam from the boiler, at a pressure of 70 to 75 pounds per square inch, enters the outer slide-case on its way to the cylinder. The periods of admission, cut-off, and exhaust are regulated by two valves, one of which works at the back of the other; the first, or expansion-valve, being a gridiron or plate valve, and the second being an ordinary slide, with the addition of two thoroughfare steam passages. In order to make the diagram more clear the letter S is marked on the spaces through which the steam passes on its way from the slide-case to the cylinder, and the letter E is marked on the exhaust passages. A series of arrows will serve to trace out the pathway of the steam, by which we note it as entering the slide case, passing out through the exhaust, and descending to the low-pressure cylinder until it finally escapes into the condenser. The whole matter is at once apparent from the drawing.

Passing on to the low-pressure cylinder, which is 83 inches in diameter, and has also a stroke of 5 feet, we find that the section here is the same as that of an ordinary double-acting condensing engine, and the only point to be noticed is the application of the double-ported construction of valve, whereby the

effective opening for steam is doubled for a given amount of travel over the ports.

The main slides of each pair of high and low-pressure cylinders are on one rod, and are worked by one pair of eccentrics with a link motion. The cut-off slide at the back of the high-pressure slide is worked by an independent eccentric.

On the platform in the front elevation are three wheels, whereof the lower one is for reversing the engines, and the upper, or star wheel, is for altering the grades of expansion, while a small wheel to be seen just over the head of the engineer is in connection with the steam regulator-valve, which is here of the double-beat type.

The air-pump is single-acting. As to valves of this construction, we may state that in the early days of the marine engine the valves connected with the air-pump were of brass; but, when screw propeller engines were introduced into the navy, and the number of revolutions made per minute by the shafting was greatly increased, it became necessary to provide valves which should be better adapted for rapid opening and closing. Accordingly, canvas valves were tried, but for only a short time, as it soon became apparent that india-rubber disc valves were much more convenient for use. The drawing (fig. 53) shows the feed valve-box of a

marine engine fitted with india-rubber valves.

It should be understood that there is a plunger pump on the side of the pipe marked A, and that the action of the pump is to suck water up through the opening at M. The lower valve E is therefore an ordinary suction valve, while the upper valve K is a delivery valve. Looking at the valve E, there is: 1, a grating,

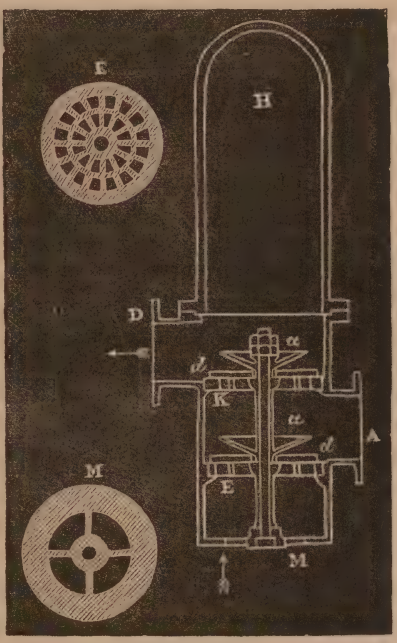


Fig. 53.

shown in plan separately at the top of the drawing, and marked E: 2, an india-rubber circular disc, shown tinted in the sketch; 3, a guard *a*, being a conical shield, which prevents the disc from rising too high when forced up by the ascent of the water. In the Allen engines, which make 200 strokes per minute, the india-rubber valves are rendered more quick in their action by means of springs fitted at the

back. There is also the delivery valve marked K, which is the exact counterpart of E. The opening for the suction is shown separately in plan, and is marked M. Also H is an air-vessel for sending forward a continuous stream of water, being a contrivance generally adopted in a force-pump.

In the present engine the air-pumps are worked from a beam connected to the piston cross-head (see fig. 51), the feed and bilge pumps being worked from the air-pump cross-head, which is provided with guide blocks.

The drawings also show, in front and side elevation, a large cylindrical vessel, which is the surface-condenser.

The condenser of Messrs. Maudslay's engine is shown in fig. 54. The tubes are of brass, and fill the large cylindrical casing shown in longitudinal and tranverse sections. They are indicated in the right-hand figure, and fill the whole empty space. The water from the circulating pump enters below, and encounters a horizontal plate, which causes it to pass through half the number of tubes, as shown by the arrows, and then the water returns to the right hand through the upper series of tubes and escapes by the overflow. In the meantime the steam is entering the space which surrounds the tubes, and becomes condensed, only to be carried away by the air-pump and again sup-

plied to the boiler. The circulating centrifugal pump is clearly shown in fig. 51; it is at the extreme right of the drawing.

The actual working of the engine will be understood from the indicator diagrams in Fig 55. The scale gives the amount of pressure in the original diagrams, which are here

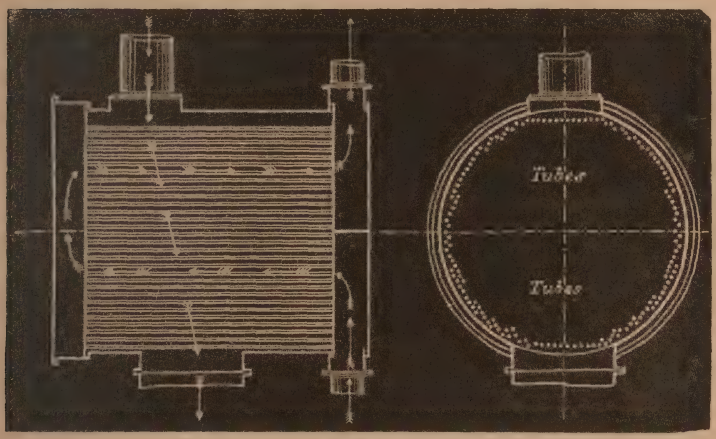


Fig. 54.

reduced in the proportion of 3° to 56. The excellence of the vacuum—viz., 28.5 inches—is especially to be noticed when taken in conjunction with the speed of the piston; for we are told that the number of revolutions is 55 to 60 per minute. The consumption of coal speaks for itself, the record of consumption for 24 hours in an actual voyage

being 96 tons, which is equivalent to 1.8 pounds of coal per horse-power per hour. So much has already been said on this subject that it is un-

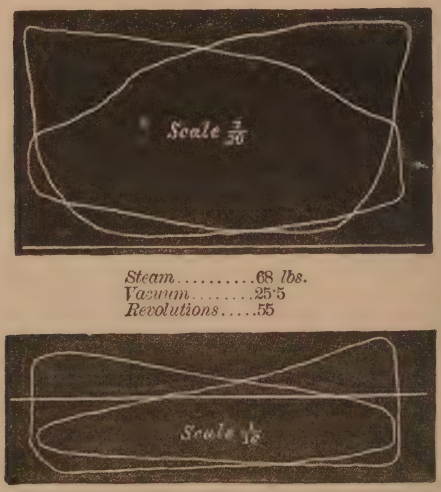
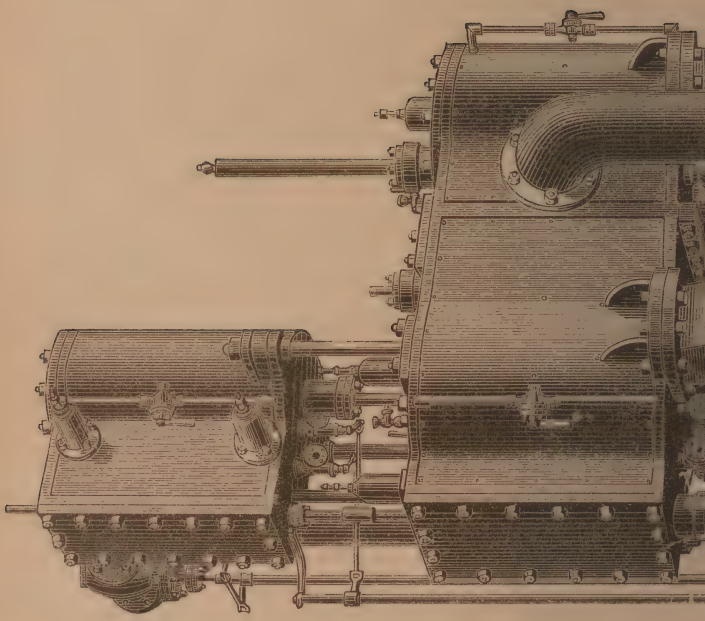
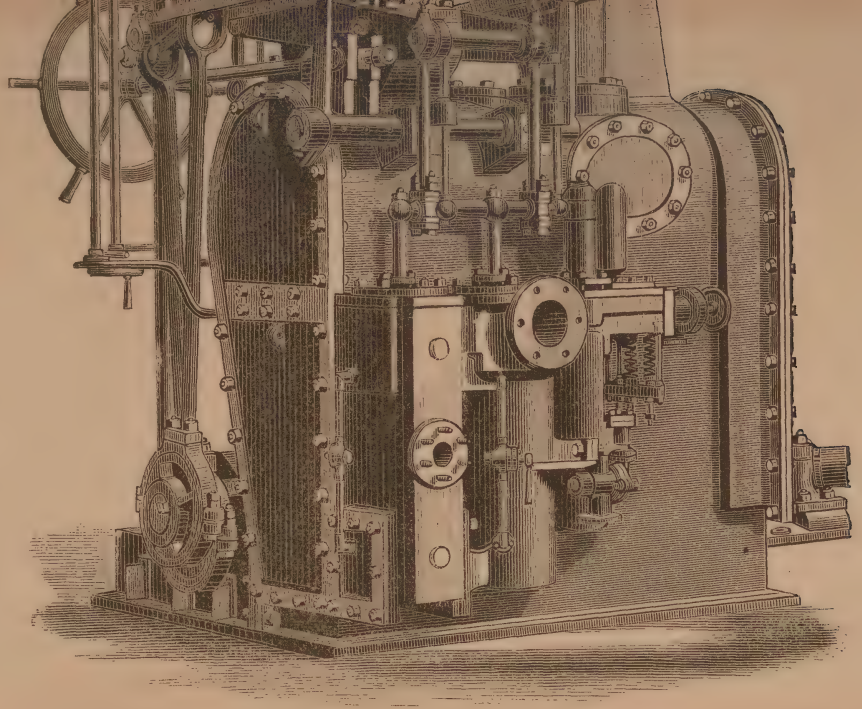


Fig. 55.

necessary to add anything further, but we may at least point out that a powerful testimony to the truth of the theory of heat is afforded by the increased economy of our resources as consequent upon a systematic endeavor to apply and put in practice the principles of that theory. It is further stated that the speed of the vessel has been maintained at 19 statute miles per hour for periods of twenty-four hours at a time.





THREE CYLINDER COMPOUND ENGINES OF THE YACHT, "ISA," (fig. 56, p. 295.)

ENGINES OF THE YACHT "ISA."

The engines and boiler of the yacht *Isa*, (see fig 56—57) the property of Mr. H. Andrews, of Newcastle-on-Tyne, and belonging to the Royal Thames Yacht Club, were built by Messrs. Douglas & Grant, engineers, Kirkcaldy, to the specification of Mr. Alex. Taylor, Newcastle.

The *Isa* is a well modeled twin screw yacht, with clipper bow and elliptic stern, 118 feet 8 inches length of keel, 18 feet 9 inches extreme breadth, 10 feet 5 inches depth moulded, and 10 feet depth of hold; flush decked, and rigged as a two-masted yacht, her yacht tonnage being 248 tons.

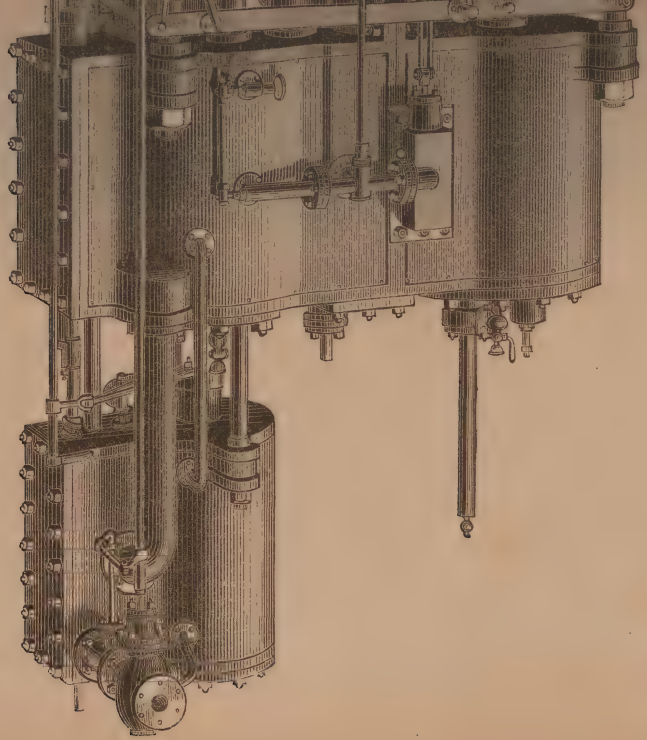
The engines are three cylinder compound, the cylinders being 10 inches, 15 inches, and 28 inches in diameter, respectively, all of 2 feet stroke. The high-pressure cylinder is placed inverted over the intermediate one, the same piston-rod serving for both, and there being space between for packing glands, etc. The cover of the intermediate cylinder is made in halves, so that its piston can be drawn without removing the high-pressure cylinder. The crank-shaft and screw-shaft are forged from Lowmoor scrap, the diameter of journals being 5 3-4 inches. The surface condenser has 350 square feet of tube surface, the tubes are three-quarter inch external diameter, packed with

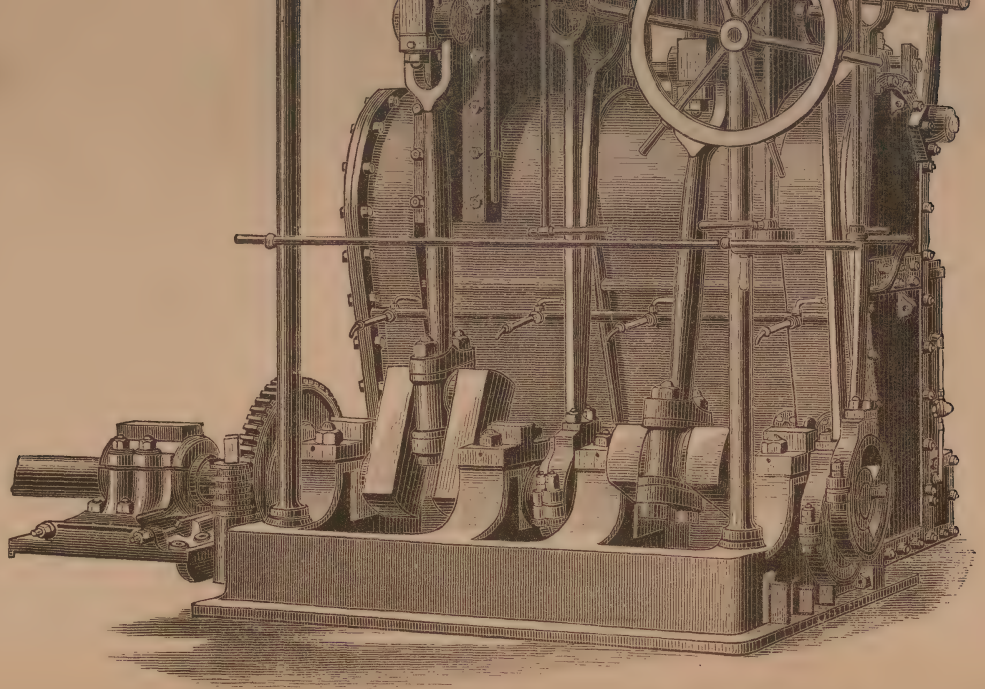
Marshall's patent rings. The air-pump is 10 1-2 inches in diameter by 12 inches stroke, and is single-acting; the circulating pump is 6 inches diameter by 12 inches stroke, and double-acting. There are two feed-pumps 1 7-8 inch in diameter by 12 inches stroke, and one bilge-pump 2 3-8 inches diameter by 12 inches stroke. The propeller has two blades and is of gun-metal, polished all over; it is 8 feet 6 inches diameter and 12 feet 3 inches pitch. Steam is supplied by one boiler 8 feet 9 inches diameter by 8 feet 6 inches long, with two furnaces 33 inches in diameter, and 106 return tubes of 2 3-4 inches external diameter. The shell plates are one inch thick, with double butt straps, treble-riveted; the boiler was proved by hydraulic pressure to 250 pounds per square inch, and with steam to 150 pounds. The working pressure is 120 pounds. The speed of the yacht is 12 knots an hour at sea.

ENGINES OF THE LARGEST COASTING STEAMER EVER BUILT IN THE UNITED STATES.

The following is taken from the *Nautical Gazette*, a paper which ought to be in the hands of every marine engineer who wishes to keep himself posted in all that relates to the profession:

"Messrs. Clark & Seaman, of the Cromwell Line of steamers, plying between New





THREE CYLINDER COMPOUND ENGINES OF THE YACHT, "ISA," (fig. 57, p. 296.)

York and New Orleans, are to have the largest steamer in the coastwise trade completed for their New Orleans line at an early date, a ship that will be the third in size ever constructed of iron in the United States—the exceptions being the *City of Peking* and *City of Tokio*, of the Pacific Mail S. S. Co. The machinery, etc., was designed by John Baird, Esq., whose marine improvements have proved so successful in the past.

"The machinery will consist of two pair of Baird's patent compound, balanced, condensing *beam* engines, with surface condensers and circulating-pump. The high-pressure cylinders are 30 inches in diameter, with 7 feet 3 inches stroke, and the low-pressure cylinders 56 inches in diameter and 6 feet stroke.

"The cylinders are fitted with double beat poppet-valves, and the valve gear similar to that now on the steamer *Hudson* of the Cromwell line.

"The surface condenser has 8,000 square feet of tube surface, the tubes being 3-4 inch in diameter, 11 feet 6 inches long, made of seamless brass, tinned both sides, fitted to act as a jet condenser, also, to inject from the bilge. The circulating-pump is operated by an independent engine. The air pump is 42 inches in diameter and 30 inches stroke, worked by a lever from the main engine.

"She will have two duplex Worthington pumps, each of a capacity of 5 gallons per stroke, to feed the boilers, pump the bilge, and to use in event of fire. There are also two bilge-pumps operated from the cross-head of the air-pump.

"The propeller shafting of first length is 17 inches in diameter, the other sections being 16 3-4 and 16 1-2 inches. The crank-pin journals are 15 inches long. The propeller is 17 feet in diameter, with four movable blades. The whole machinery will be a marvel of beauty, finish, and novelty, and will doubtless be the perfection of marine engineering skill in this direction.

"There will be eight round cylindrical boilers, known as 'Baird's patent,' two in a 'nest,' with a water-jacket between each; they are 8 feet 6 inches in diameter, 12 feet 2 inches in length over all, with 3 inch tubes, 10 feet long, No. 9 thick. The boilers will be placed on each side of the vessel, with the fire-room running longitudinally between them. Each four boilers will have a vertical steam drum, 7 feet in diameter and 13 feet high.

"The shells of the boiler are 1-2 inch thick, the longitudinal seams double-riveted. The tube sheets are 5-8 inch thick. There will be two smoke stacks, each fitted with a Nicholson jet, and each boiler will have a Hancock inspirator."

APPENDIX.

Algebraic Signs as applied in Mechanical Calculations.

=Sign of equality, and signifies equal to, as 2 added to 5=7.
+Sign of addition, and signifies plus or more, as 4+2=6.
−Sign of subtraction, and signifies minus or less, as 7−5 =2.
×Sign of multiplication, and signifies multiplied by, as 7×6 =42.
÷Sign of division, and signifies divided by, as 20÷5=4.
√Sign of square root, ∛Sign of cube root } evolution, or the extraction of roots, thus √81=9 ∛729 =9.

Fractions of a foot	Decimal Value in Feet.	Area in Feet.	Circumference in feet.	Fractions of an Inch.	Decimal Value.	Fractions of an Inch.	Decimal Value.
11	.9166	.6598	2.879	7/8 & 3/32	.96875	7/8 & 3/32	.40875
10	.8333	.54537	2.617	7/8 & 1/16	.9375	7/8 & 1/16	.4375
9	.75	.44178	2.356	7/8 & 1/32	.90625	7/8 & 1/32	.40625
8	.6666	.33779	2.094	7/8	.875	3/8 & 3/32	.375
7	.5833	.26722	1.832	3/4 & 3/32	.84375	3/4 & 3/32	.34375
6	.5	.19635	1.57	3/4 & 1/16	.8125	3/4 & 1/16	.3125
5	.4166	.1363	1.308	3/4 & 1/32	.78125	3/4 & 1/32	.28125
4	.3333	.08724	1.047	3/4	.75	1/4 & 3/32	.25
3	.25	.04908	.7854	5/8 & 3/32	.71875	1/4 & 3/32	.21875
2	.1666	.02179	.5233	5/8 & 1/16	.6875	1/4 & 1/16	.1875
1	.0833	.00544	.2616	5/8 & 1/32	.65625	1/4 & 1/32	.15625
7/8	.07291	.00417	.22907	5/8	.625	1/8 & 3/32	.125
3/4	.0625	.00306	.19635	1/2 & 3/32	.59375	1/8 & 1/16	.09375
5/8	.05208	.0028	.16362	1/2 & 1/16	.5625	1/8 & 1/32	.0625
1/2	.04166	.00136	.130899	1/2 & 1/32	.53125	1/16 & 1/32	.03125
3/8	.03125	.00076	.098174	1/2	.5		
1/4	.02083	.00035	.06545				
1/8	.01041	.000085	.032719				

A Table of Diameters, Areas, and Circumferences of Circles, from $\frac{1}{16}$ of an Inch to 110 Inches.

Dia.	Area.	Circum.	Dia.	Area.	Circum.
$\frac{1}{16}$	.0030	.1963	$\frac{5}{16}$	4.2001	7.2649
$\frac{1}{8}$	.0122	.3927	$\frac{3}{8}$	4.4302	7.4613
$\frac{3}{16}$	.0276	.5890	$\frac{7}{16}$	4.6664	7.6576
$\frac{1}{4}$	.0490	.7854	$\frac{1}{2}$	4.9087	7.8540
$\frac{5}{16}$	.0767	.9817	$\frac{9}{16}$	5.1573	8.0503
$\frac{3}{8}$	.1104	1.1781	$\frac{5}{8}$	5.4119	8.2467
$\frac{7}{16}$	.1503	1.3744	$\frac{11}{16}$	5.6727	8.4430
$\frac{1}{2}$	.1963	1.5708	$\frac{3}{4}$	5.9395	8.6394
$\frac{9}{16}$	.2485	1.7671	$\frac{13}{16}$	6.2126	8.8357
$\frac{5}{8}$	.3068	1.9635	$\frac{7}{8}$	6.4918	9.0321
$\frac{11}{16}$	.3712	2.1598	$\frac{15}{16}$	6.7772	9.2284
$\frac{3}{4}$	.4417	2.3562			
$\frac{13}{16}$	.5185	2.5525	3 in.	7.0686	9.4248
$\frac{7}{8}$	.6013	2.7489	$\frac{1}{16}$	7.3662	9.6211
$\frac{15}{16}$	.6903	2.9452	$\frac{1}{8}$	7.6699	9.8175
			$\frac{3}{16}$	7.9798	10.0138
1 in.	.7854	3.1416	$\frac{1}{4}$	8.2957	10.2102
$\frac{1}{16}$	.8861	3.3379	$\frac{5}{16}$	8.6179	10.4065
$\frac{1}{8}$	.9940	3.5343	$\frac{3}{8}$	8.9462	10.6029
$\frac{3}{16}$	1.1075	3.7306	$\frac{7}{16}$	9.2806	10.7992
$\frac{1}{4}$	1.2271	3.9270	$\frac{1}{2}$	9.6211	10.9956
$\frac{5}{16}$	1.3529	4.1233	$\frac{9}{16}$	9.9678	11.1919
$\frac{3}{8}$	1.4848	4.3197	$\frac{5}{8}$	10.3206	11.3883
$\frac{7}{16}$	1.6229	4.5160	$\frac{11}{16}$	10.6796	11.5846
$\frac{1}{2}$	1.7671	4.7124	$\frac{3}{4}$	11.0446	11.7810
$\frac{9}{16}$	1.9175	4.9087	$\frac{13}{16}$	11.4159	11.9773
$\frac{5}{8}$	2.0739	5.1051	$\frac{7}{8}$	11.7932	12.1737
$\frac{11}{16}$	2.2365	5.3014	$\frac{15}{16}$	12.1768	12.3700
$\frac{3}{4}$	2.4052	5.4978			
$\frac{13}{16}$	2.5801	5.6941	4 in.	12.5664	12.5664
$\frac{7}{8}$	2.7611	5.8905	$\frac{1}{16}$	12.9622	12.7627
$\frac{15}{16}$	2.9483	6.0868	$\frac{1}{8}$	13.3640	12.9591
			$\frac{3}{16}$	13.7721	13.1554
2 in.	3.1416	6.2832	$\frac{1}{4}$	14.1862	13.3518
$\frac{1}{16}$	3.3411	6.4795	$\frac{5}{16}$	14.6066	13.5481
$\frac{1}{8}$	3.5465	6.6759	$\frac{3}{8}$	15.0331	13.7445
$\frac{3}{16}$	3.7582	6.8722	$\frac{7}{16}$	15.4657	13.9408
$\frac{1}{4}$	3.9760	7.0686	$\frac{1}{2}$	15.9043	14.1372

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
9/16	16.3492	14.3335	7 in.	38.4846	21.9912
5/8	16.8001	14.5299	1/16	39.1749	22.1875
11/16	17.2573	14.7262	1/8	39.8713	22.3839
3/4	17.7205	14.9226	3/16	40.5469	22.5802
13/16	18.1900	15.1189	1/4	41.2825	22.7766
7/8	18.6655	15.3153	5/16	41.9974	22.9729
15/16	19.1472	15.5716	3/8	42.7184	23.1693
			7/16	43.4455	23.3656
5 in.	19.6350	15.7080	1/2	44.1787	23.5620
1/16	20.1290	15.9043	9/16	44.9181	23.7583
1/8	20.6290	16.1007	5/8	45.6636	23.9547
3/16	21.1252	16.2970	11/16	46.4153	24.1510
1/4	21.6475	16.4934	3/4	47.1730	24.3474
5/16	22.1661	16.6897	13/16	47.9370	24.5437
3/8	22.6907	16.8861	7/8	48.7070	24.7401
7/16	23.2215	17.0824	15/16	49.4833	24.9364
1/2	23.7583	17.2788			
9/16	24.3014	17.4751	8 in.	50.2656	25.1328
5/8	24.8505	17.6715	1/16	51.0541	25.3291
11/16	25.4058	17.8678	1/8	51.8486	25.5255
3/4	25.9672	18.0642	3/16	52.8994	25.7218
13/16	26.5348	18.2605	1/4	53.4562	25.9182
7/8	27.1085	18.4569	5/16	54.2748	26.1145
15/16	27.6884	18.6532	3/8	55.0885	26.3109
			7/16	55.9138	26.5072
6 in.	28.2744	18.8496	1/2	56.7451	26.7036
1/16	28.8665	19.0459	9/16	57.5887	26.8999
1/8	29.4647	19.2423	5/8	58.4264	27.0963
3/16	30.0798	19.4386	11/16	59.7762	27.2926
1/4	30.6796	19.6350	3/4	60.1321	27.4890
5/16	31.2964	19.8313	13/16	60.9943	27.6853
3/8	31.9192	20.0277	7/8	61.8625	27.8817
7/16	32.5481	20.2240	15/16	62.7369	28.0780
1/2	33.1831	20.4204			
9/16	33.8244	20.6167	9 in.	63.6174	28.2744
5/8	34.4717	20.8131	1/16	64.5041	28.4707
11/16	35.1252	21.0094	1/8	65.3968	28.6671
3/4	35.7847	21.2058	3/16	66.2957	28.8634
13/16	36.4505	21.4021	1/4	67.2007	29.0598
7/8	37.1224	21.5985	5/16	68.1120	29.2561
15/16	37.8005	21.7948	3/8	69.0293	29.4525
			7/16	69.9528	29.6488

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
½	70.8823	29.8452	12 in.	113.0976	37.6992
9/16	71.8181	30.0415	1/16	114.2788	37.8955
⅝	72.7599	30.2379	⅛	115.4660	38.0919
11/16	73.7079	30.4342	3/16	116.6645	38.2882
¾	74.6620	30.6306	¼	117.8590	38.4846
13/16	75.6223	30.8269	5/16	119.0648	38.6809
⅞	76.5887	31.0233	⅜	120.2766	38.8773
15/16	77.5613	31.2196	7/16	121.4946	39.0736
			½	122.7187	39.2700
10 in.	78.5400	31.4160	9/16	123.9490	39.4663
1/16	79.5248	31.6123	⅝	125.1854	39.6627
⅛	80.5157	31.8087	11/16	126.4479	39.8590
3/16	81.5128	32.0050	¾	127.6765	40.0554
¼	82.5160	32.2014	13/16	128.8999	40.2517
5/16	83.5254	32.3977	⅞	130.1923	40.4481
⅜	84.5409	32.5941	15/16	131.4279	40.6444
7/16	85.5626	32.7904			
½	86.5903	32.9868	13 in.	132.7326	40.8408
9/16	87.6243	33.1831	1/16	134.0120	41.0371
⅝	88.6643	33.3795	⅛	135.2974	41.2338
11/16	89.7105	33.5758	3/16	136.5890	41.4298
¾	90.7627	33.7722	¼	137.8867	41.6262
13/16	91.8212	33.9685	5/16	139.1907	41.8225
⅞	92.8858	34.1649	⅜	140.5007	42.0189
15/16	93.9566	34.3612	7/16	141.8169	42.2152
			½	143.1391	42.4116
11 in.	95.0334	34.5596	9/16	144.4726	42.6079
1/16	96.1164	34.7539	⅝	145.8021	42.8043
⅛	97.2053	34.9503	11/16	147.1428	43.0006
3/16	98.3008	35.1466	¾	148.4896	43.1970
¼	99.4021	35.3430	13/16	149.8426	43.3933
5/16	100.5097	35.5393	⅞	151.2017	43.5897
⅜	101.6234	35.7357	15/16	152.5670	43.7860
7/16	102.7432	35.9320			
½	103.8691	36.1284	14 in.	153.9384	43.9824
9/16	105.0012	36.3247	1/16	155.3159	44.1787
⅝	106.1394	36.5211	⅛	156.6995	44.3751
11/16	107.2838	36.7174	3/16	158.0893	44.5714
¾	108.4342	36.9138	¼	159.4852	44.7676
13/16	109.5909	37.1101	5/16	160.8374	44.9641
⅞	110.7536	37.3065	⅜	162.2956	45.1605
15/16	111.9226	37.5028	7/16	163.7099	45.3568

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	165.1303	45.5532	17 in.	226.9806	53.4072
9/16	166.5569	45.7495	1/16	228.6527	53.6035
5/8	167.9896	45.9459	1/8	230.3308	53.7999
1 1/16	169.4285	46.1422	3/16	232.0151	53.9962
3/4	170.8735	46.3386	1/4	233.7055	54.1926
1 3/16	172.3247	46.5349	5/16	235.4022	54.3889
7/8	173.7820	46.7313	3/8	237.1049	54.5853
1 15/16	175.2455	46.9276	7/16	238.8138	54.7816
			1/2	240.5287	54.9780
15 in.	176.7150	47.1240	9/16	242.2499	55.1743
1/16	178.1907	47.3203	5/8	243.9771	55.3707
1/8	179.6725	47.5167	1 1/16	245.7105	55.5670
3/16	181.1105	47.7130	3/4	247.4500	55.7634
1/4	182.6545	47.9094	1 3/16	249.1952	55.9597
5/16	184.1548	48.1057	7/8	250.9475	56.1561
3/8	185.6612	48.3021	1 15/16	252.7050	56.3524
7/16	187.1737	48.4984			
1/2	188.6923	48.6948	18 in.	254.4696	56.5488
9/16	190.2171	48.8911	1/16	256.2398	56.7451
5/8	191.7480	49.0875	1/8	258.0161	56.9415
1 1/16	193.3351	49.2838	3/16	259.7986	57.1378
3/4	194.8282	49.4802	1/4	261.5872	57.3342
1 3/16	196.3776	49.6765	5/16	263.3820	57.5305
7/8	197.9330	49.8729	3/8	265.1829	57.7269
1 15/16	199.4947	50.0692	7/16	266.9900	57.9282
			1/2	268.8031	58.1196
16 in.	201.0624	50.2656	9/16	270.6225	58.2159
1/16	202.6363	50.4619	5/8	272.4479	58.5123
1/8	204.2162	50.6583	1 1/16	274.2895	58.7806
3/16	205.8024	50.8546	3/4	276.1171	58.9056
1/4	207.3946	51.0510	1 3/16	277.9610	59.1013
5/16	208.9931	51.2473	7/8	279.8110	59.2977
3/8	210.5976	51.4437	1 15/16	281.1672	59.4940
7/16	212.2083	51.6400			
1/2	213.8251	51.8364	19 in.	283.5294	59.6904
9/16	215.4481	52.0327	1/16	285.3978	59.8867
5/8	217.0772	52.2291	1/8	287.2723	60.0831
1 1/16	218.7124	52.4254	3/16	289.4030	60.2794
3/4	220.3537	52.6218	1/4	291.0397	60.4758
1 3/16	222.0013	52.8181	5/16	292.9324	60.6721
7/8	223.6549	53.0145	3/8	294.8312	60.8685
1 15/16	225.3147	53.2108	7/16	296.7367	61.0648

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	298.6483	61.2612	22 in.	380.1336	69.1152
1 9/16	300.5658	61.4575	1 1/16	382.2965	69.3115
5/8	302.4894	61.6539	1/8	384.4655	69.5079
1 1/16	304.4192	61.8502	1 3/16	386.6907	69.7042
1/4	306.3550	62.0466	1/4	388.8220	69.9006
1 3/16	308.2971	62.2429	1 5/16	391.0095	70.0969
7/8	310.2452	62.4393	3/8	393.2031	70.2933
1 5/16	312.1996	62.6356	1 7/16	395.4029	70.4806
			1/2	397.6087	70.6860
20 in.	314.1600	62.8320	1 9/16	399.8207	70.8823
1 1/16	316.1266	63.0283	5/8	402.0388	71.0787
1/8	318.0992	63.2247	1 1/16	404.2631	71.2750
1 3/16	320.0781	63.4210	3/4	406.4935	71.4714
1/4	322.0630	63.6174	1 3/16	408.7301	71.6677
1 5/16	324.0542	63.8137	7/8	410.9728	71.8641
3/8	326.0514	64.0101	1 5/16	413.2317	72.0604
1 7/16	328.0548	64.2064			
1/2	330.0643	64.4028	23 in.	415.4766	72.2568
1 9/16	332.0800	64.5991	1 1/16	417.7377	72.4531
5/8	334.1018	64.7955	1/8	420.0049	72.6495
1 1/16	336.1297	64.9918	1 3/16	422.2783	72.8458
3/4	338.1637	65.1882	1/4	424.5577	73.0422
1 3/16	340.2040	65.3845	1 5/16	426.3434	73.2385
7/8	342.2502	65.5809	3/8	429.1352	73.4349
1 5/16	344.3028	65.7772	1 7/16	431.4331	73.6312
			1/2	433.7371	73.8276
21 in.	346.3614	65.7936	1 9/16	436.0473	74.0239
1 1/16	348.4267	66.1699	5/8	438.3636	74.2203
1/8	350.4970	66.3663	1 1/16	440.6811	74.4166
1 3/16	352.5740	66.5626	3/4	443.0146	74.6130
1/4	354.6571	66.7590	1 3/16	445.3539	74.8093
1 5/16	356.7465	66.9553	7/8	447.6992	75.0057
3/8	358.8419	67.1517	1 5/16	450.0418	75.2020
1 7/16	360.9435	67.3480			
1/2	363.0511	67.5444	24 in.	452.3904	75.3984
1 9/16	365.1650	67.7407	1 1/16	454.7497	75.5947
5/8	367.2849	67.9371	1/8	457.1150	75.7911
1 1/16	369.4110	68.1334	1 3/16	459.4866	75.9874
3/4	371.5432	68.3298	1/4	461.8642	76.1838
1 3/16	373.6816	68.5261	1 5/16	464.2481	76.3801
7/8	375.8261	68.7225	3/8	466.6380	76.5765
1 5/16	377.9768	68.9188	1 7/16	469.0341	76.7728

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	471.4363	76.9692	27 in.	572.5566	84.8232
1/16	473.8447	77.1655	1/16	575.2104	85.0195
1/8	476.2592	77.3619	1/8	577.8703	85.2159
1 1/16	478.6798	77.5582	3/16	580.5364	85.4122
3/4	481.1065	77.7546	1/4	583.2085	85.6086
1 3/16	483.5395	77.9509	5/16	585.8869	85.8049
7/8	485.9785	78.1473	3/8	588.5714	86.0013
1 5/16	488.4237	78.3436	7/16	591.2620	86.1976
			1/2	593.9587	86.3940
25 in.	490.8750	78.5400	9/16	596.6616	86.5903
1/16	493.3325	78.7363	5/8	599.3706	86.7867
1/8	495.7960	78.9327	1 1/16	602.0858	86.9830
3/16	498.2657	79.1290	3/4	604.8070	87.1794
1/4	500.7415	79.3254	1 3/16	607.5345	87.3757
5/16	503.2236	79.5217	7/8	610.2680	87.5721
3/8	505.7117	79.7181	1 5/16	613.0078	87.7684
7/16	508.2060	79.9144			
1/2	510.7063	80.1108	28 in.	615.7536	87.9648
9/16	513.2129	80.3071	1/16	618.5051	88.1611
5/8	515.7255	80.5035	1/8	621.2636	88.3575
1 1/16	518.2443	80.6998	3/16	624.0279	88.5538
3/4	520.7692	80.8962	1/4	626.7982	88.7502
1 3/16	523.3003	81.0925	5/16	629.5748	88.9465
7/8	525.8375	81.2889	3/8	632.3574	89.1429
1 5/16	528.3809	81.4852	7/16	635.1462	89.3392
			1/2	637.9411	89.5356
26 in.	530.9304	81.6816	9/16	640.7422	89.7319
1/16	533.4860	81.8779	5/8	643.5494	89.9283
1/8	536.0477	82.0743	1 1/16	646.3627	90.1246
3/16	538.6156	82.2706	3/4	649.1821	90.3210
1/4	541.1896	82.4670	1 3/16	652.0078	90.5173
5/16	543.7698	82.6633	7/8	654.8395	90.7137
3/8	546.3561	82.8597	1 5/16	657.6774	90.9100
7/16	548.9486	83.0560			
1/2	551.5471	83.2524	29 in.	660.5214	91.1064
9/16	554.1519	83.4487	1/16	663.3716	91.3027
5/8	556.7627	83.6451	1/8	666.2278	91.4991
1 1/16	559.3797	83.8414	3/16	669.0902	91.6954
3/4	562.0027	84.0378	1/4	671.9587	91.8918
1 3/16	564.6320	84.2341	5/16	674.8335	92.0081
7/8	567.2674	84.4305	3/8	677.7143	92.2845
1 5/16	569.4090	84.6268	7/16	680.6013	92.4808

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
½	683.4943	92.6772	32 in.	804.2496	100.5312
9/16	686.3936	92.8735	1/16	807.3943	100.7275
⅝	689.2989	93.0699	⅛	810.5450	100.9240
1/16	692.2104	93.2662	3/16	813.7020	101.1202
¾	695.1280	93.4626	¼	816.8650	101.3166
13/16	698.0518	93.6589	5/16	820.0343	101.5130
⅞	700.9817	93.8553	⅜	823.2096	101.7093
15/16	703.9178	94.0516	7/16	826.3911	101.9056
			½	829.5787	102.1020
30 in	706.8600	94.2480	9/16	832.7725	102.2983
1/16	709.8083	94.4443	⅝	835.9724	102.4947
⅛	712.7627	94.6407	11/16	839.1784	102.6910
3/16	715.7233	94.8370	¾	842.3905	102.8874
¼	718.6900	95.0334	13/16	845.6089	103.0837
5/16	721.6629	95.2297	⅞	848.8333	103.2801
⅜	724.6419	95.4261	15/16	852.0639	103.4764
7/16	727.6271	95.6224			
½	730.6183	95.8188	33 in.	855.3006	103.6728
9/16	733.6158	96.0151	1/16	858.5436	103.8691
⅝	736.6193	96.2115	⅛	861.7924	104.0655
11/16	739.6290	96.4078	3/16	865.0475	104.2618
¾	742.6447	96.6042	¼	868.3087	104.4582
13/16	745.6667	96.8005	5/16	871.5760	104.6545
⅞	748.6948	96.9969	⅜	874.8497	104.8509
15/16	751.7291	97.1932	7/16	878.1290	105.0472
			½	881.4151	105.2436
31 in.	754.7694	97.3896	9/16	884.7070	105.4399
1/16	757.8159	97.5859	⅝	888.0051	105.6363
⅛	760.8685	97.7823	11/16	891.3090	105.8326
3/16	763.9273	97.9786	¾	894.6196	106.0290
¼	766.9921	98.1750	13/16	897.9369	106.2253
5/16	770.0632	98.3713	⅞	901.2587	106.4217
⅜	773.1404	98.5677	15/16	904.5875	106.6180
7/16	776.2237	98.7648			
½	779.3131	98.9684	34 in.	907.9224	106.8144
9/16	782.4087	99.1567	1/16	911.2645	107.0107
⅝	785.5104	99.3531	⅛	914.6105	107.2071
11/16	788.6183	99.5494	3/16	917.9640	107.4034
¾	791.7322	99.7458	¼	921.3232	107.5998
13/16	794.8524	99.9421	5/16	924.6883	107.7961
⅞	797.9786	100.1385	⅜	928.0605	107.9925
15/16	801.1111	100.3348	7/16	931.4380	108.1888

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	934.8223	108.3852	37 in.	1075.2126	116.2392
1/16	938.2121	108.5815	1/16	1078.8482	116.4355
1/8	941.6087	108.7779	1/8	1082.4898	116.6319
1 1/16	945.0110	108.9742	3/16	1086.1376	116.8282
3/4	948.4195	109.1706	1/4	1089.7915	117.0246
1 3/16	951.8341	109.3669	5/16	1093.4517	117.2209
1 1/8	955.2550	109.5633	3/8	1097.1179	117.4173
1 5/16	958.6820	109.7596	7/16	1100.7903	117.6136
			1/2	1104.4687	117.8100
35 in.	962.1150	109.9560	9/16	1108.1534	118.0063
1/16	965.5542	110.1523	5/8	1111.8441	118.2027
1/8	968.9995	110.3487	1 1/16	1115.5410	118.3990
3/16	972.4510	110.5450	3/4	1119.2440	118.5954
1/4	975.9085	110.7414	1 3/16	1122.9532	118.7917
5/16	979.3686	110.9377	1 1/8	1126.6685	118.9881
3/8	982.8422	111.1341	1 5/16	1130.3900	119.1844
7/16	986.3180	111.3304			
1/2	989.8003	111.5268	38 in.	1134.1176	119.3808
9/16	993.2097	111.7231	1/16	1137.8513	119.5771
5/8	996.7830	111.9195	1/8	1141.5911	119.7735
1 1/16	1000.3472	112.1158	3/16	1145.3371	119.9698
3/4	1003.7902	112.3122	1/4	1149.0892	120.1662
1 3/16	1007.3030	112.5086	5/16	1152.8475	120.3625
1 1/8	1010.8220	112.7049	3/8	1156.6119	120.5589
1 5/16	1014.3472	112.9012	7/16	1160.3825	120.7552
			1/2	1164.1591	120.9516
36 in.	1017.8784	113.0976	9/16	1167.9420	121.1479
1/16	1021.4158	113.2939	5/8	1171.7309	121.3443
1/8	1024.9592	113.4903	1 1/16	1175.5260	121.5406
3/16	1028.5089	113.6866	3/4	1179.3271	121.7370
1/4	1032.0646	113.8830	1 3/16	1183.1345	121.9333
5/16	1035.6266	114.0793	1 1/8	1186.9480	122.1297
3/8	1039.1946	114.2757	1 5/16	1190.7677	122.3260
7/16	1042.7913	114.4720			
1/2	1046.3941	114.6684	39 in.	1194.5934	122.5224
9/16	1049.9581	114.8647	1/16	1198.4253	122.7187
5/8	1053.5281	115.0611	1/8	1202.2633	122.9151
1 1/16	1057.1269	115.2572	3/16	1206.1075	123.1114
3/4	1060.7317	115.4538	1/4	1209.9577	123.3078
1 3/16	1064.3428	115.6501	5/16	1213.8142	123.5041
1 1/8	1067.9599	115.8465	3/8	1217.6768	123.7005
1 5/16	1071.5832	116.0428	7/16	1221.5455	123.8968

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
½	1225.4203	124.0932	42 in.	1385.4456	131.9472
9/16	1229.3013	124.2895	1/16	1389.5720	132.1435
5/8	1233.1884	124.4859	1/8	1393.7045	132.3399
11/16	1237.0817	124.6822	3/16	1397.8432	132.5362
3/4	1240.9810	124.8786	¼	1401.9880	132.7326
13/16	1244.8866	125.0749	5/16	1406.1390	132.9289
7/8	1248.7982	125.2713	3/8	1410.2961	133.1253
15/16	1252.7161	125.4676	7/16	1414.4594	133.3216
			½	1418.6287	133.5180
40 in.	1256.6400	125.6640	9/16	1422.8043	133.7143
1/16	1260.5701	125.8603	5/8	1426.9859	133.9107
1/8	1264.5062	126.0567	11/16	1431.1737	134.1070
3/16	1268.4486	126.2530	¾	1435.3675	134.3034
¼	1272.3970	126.4494	13/16	1439.5676	134.4997
5/16	1276.3517	126.6457	7/8	1443.7738	134.6961
3/8	1280.3124	126.8421	15/16	1447.9862	134.8924
7/16	1284.2793	127.0384			
½	1288.2523	127.2348	43 in.	1452.2046	135.0888
9/16	1292.2315	127.4311	1/16	1456.4292	135.2851
5/8	1296.2168	127.6275	1/8	1460.6599	135.4815
11/16	1300.2082	127.8238	3/16	1464.8968	135.6778
¾	1304.2057	128.0202	¼	1469.1397	135.8742
13/16	1308.2095	128.2165	5/16	1473.3839	136.0705
7/8	1312.2193	128.4129	3/8	1477.6342	136.2669
15/16	1316.2353	128.6092	7/16	1481.9006	136.4632
			½	1486.1731	136.6596
41 in.	1320.2574	128.8056	9/16	1490.4468	136.8559
1/16	1324.2857	129.0019	5/8	1494.7266	137.0523
1/8	1328.3200	129.1983	11/16	1499.0126	137.2486
3/16	1332.3605	129.3946	¾	1503.3046	137.4450
¼	1336.4071	129.5910	13/16	1507.6029	137.6413
5/16	1340.4600	129.7873	7/8	1511.9072	137.8377
3/8	1344.5189	129.9837	15/16	1516.2178	138.0340
7/16	1348.5840	130.1800			
½	1352.6551	130.3764	44 in.	1520.5344	138.2304
9/16	1356.7325	130.5727	1/16	1524.8572	138.4267
5/8	1360.8159	130.7691	1/8	1529.1860	138.6231
11/16	1364.9055	130.9654	3/16	1533.5211	138.8194
¾	1369.0012	131.1618	¼	1537.8622	139.0158
13/16	1373.1031	131.3581	5/16	1542.2046	139.2121
7/8	1377.2111	131.5545	3/8	1546.5530	139.4085
15/16	1381.3253	131.7508	7/16	1550.9176	139.6048

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	1555.2883	139.8012	47 in.	1734.9486	147.6552
9/16	1559.6602	139.9975	1/16	1739.5659	147.8515
5/8	1564.0382	140.1939	1/8	1744.1893	148.0479
11/16	1568.4223	140.3902	3/16	1748.8189	148.2442
3/4	1572.8125	140.5866	1/4	1753.4545	148.4406
13/16	1577.2090	140.7829	5/16	1758.0914	148.6369
7/8	1581.6115	140.9793	3/8	1762.7344	148.8333
15/16	1586.0203	141.1756	7/16	1767.3935	149.0296
			1/2	1772.0587	149.2260
45 in.	1590.4350	141.3720	9/16	1776.7251	149.4223
1/16	1594.4560	141.5683	5/8	1781.3976	149.6187
1/8	1599.2830	141.7647	11/16	1786.0763	149.8150
3/16	1603.7162	141.9610	3/4	1790.7610	150.0114
1/4	1608.1555	142.1574	13/16	1795.4520	150.2077
5/16	1612.5961	142.3537	7/8	1800.1490	150.4041
3/8	1617.0427	142.5501	15/16	1804.8523	150.6004
7/16	1621.5055	142.7464			
1/2	1625.9743	142.9428	48 in.	1809.5616	150.7968
9/16	1630.4444	143.1391	1/16	1814.2551	150.9931
5/8	1634.9205	143.3355	1/8	1818.9986	151.1895
11/16	1639.4028	143.5318	3/16	1823.7264	151.3858
3/4	1643.8912	143.7282	1/4	1828.4602	151.5822
13/16	1648.3858	143.9245	5/16	1833.1953	151.7785
7/8	1652.8865	144.1209	3/8	1837.9364	151.9749
15/16	1657.3934	144.3172	7/16	1842.6937	152.1712
			1/2	1847.4571	152.3676
46 in.	1661.9064	144.5136	9/16	1852.2167	152.5639
1/16	1666.4255	144.7099	5/8	1856.9924	152.7603
1/8	1670.9507	144.9063	11/16	1861.7892	152.9566
3/16	1675.4821	145.1026	3/4	1868.5521	153.1530
1/4	1680.0196	145.2990	13/16	1871.3413	153.3493
5/16	1684.5583	145.4953	7/8	1876.1365	153.5457
3/8	1689.1031	145.6917	15/16	1880.9379	153.7420
7/16	1693.6641	145.8880			
1/2	1698.2311	146.0844	49 in.	1885.7454	153.9384
9/16	1702.7994	146.2807	1/16	1890.5591	154.1347
5/8	1707.3737	146.4771	1/8	1895.3788	154.3311
11/16	1711.9542	146.6734	3/16	1900.2047	154.5274
3/4	1716.5407	146.8698	1/4	1905.0367	154.7238
13/16	1721.1335	147.0661	5/16	1909.8700	154.9201
7/8	1725.7324	147.2625	3/8	1914.7093	155.1165
15/16	1730.3375	147.4588	7/16	1919.5648	155.3128

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	1924.4263	155.5092	52 in.	2123.7216	163.3632
9/16	1929.2891	155.7055	1/16	2128.8298	163.5595
5/8	1934.1579	155.9019	1/8	2133.9440	163.7559
11/16	1939.0329	156.0982	3/16	2139.0645	163.9522
3/4	1943.9140	156.2946	1/4	2144.1910	164.1486
13/16	1948.8013	156.4909	5/16	2149.3238	164.3449
7/8	1953.6947	156.6873	3/8	2154.4626	164.5413
15/16	1958.0943	156.8836	7/16	2159.6076	164.7376
			1/2	2164.7587	164.9340
50 in.	1963.5000	157.0800	9/16	2169.9160	165.1303
1/16	1968.4118	157.2763	5/8	2175.0794	165.3267
1/8	1973.3297	157.4727	11/16	2180.2489	165.5230
3/16	1978.2525	157.6690	3/4	2185.4245	165.7194
1/4	1983.1840	157.8654	13/16	2190.6064	165.9157
5/16	1988.6154	158.0617	7/8	2195.7943	166.1121
3/8	1993.0529	158.2581	15/16	2200.9884	166.3084
7/16	1998.0066	158.4544			
1/2	2002.9663	158.6508	53 in.	2206.1886	166.5048
9/16	2007.9273	158.8471	1/16	2211.3950	166.7011
5/8	2012.8943	159.0435	1/8	2216.6074	166.8975
11/16	2017.8675	159.2398	3/16	2221.8260	167.0938
3/4	2022.8467	159.4362	1/4	2227.0507	167.2902
13/16	2027.8172	159.6325	5/16	2232.2817	167.4865
7/8	2032.8238	159.8289	3/8	2237.5187	167.6829
15/16	2037.8216	160.0252	7/16	2242.7619	167.8792
			1/2	2248.0111	168.0756
51 in.	2042.8254	160.2216	9/16	2253.2666	168.2719
1/16	2047.8354	160.4179	5/8	2258.5281	168.4683
1/8	2052.8515	160.6143	11/16	2263.7908	168.6646
3/16	2057.8798	160.8106	3/4	2269.0696	168.8610
1/4	2062.9021	161.0070	13/16	2274.3496	169.0573
5/16	2067.9317	161.2033	7/8	2279.6357	169.2537
3/8	2072.9674	161.3997	15/16	2284.9280	169.4500
7/16	2078.0293	161.5960			
1/2	2083.0771	161.7924	54 in.	2290.2264	169.6464
9/16	2088.1362	161.9887	1/16	2295.5309	169.8427
5/8	2093.2014	162.1851	1/8	2300.8415	170.0391
11/16	2098.2678	162.3814	3/16	2306.1583	170.2354
3/4	2103.3502	162.5778	1/4	2311.4812	170.4318
13/16	2108.4339	162.7741	5/16	2316.8163	170.6281
7/8	2113.5236	162.9705	3/8	2322.1455	170.8245
15/16	2118.1196	163.1668	7/16	2327.4819	171.0208

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
55 in.	2375.8350	172.7880	58 in.	2642.0856	182.2128
	2381.2382	172.9843		2647.7328	182.4091
	2386.6465	173.1807		2653.4861	182.6055
	2392.0515	173.3770		2659.9565	182.8018
	2397.4825	173.5734		2664.9112	182.9982
	2402.9098	173.7697		2670.6330	183.1945
	2408.3432	173.9661		2676.3609	183.3909
	2413.7777	174.1624		2682.0950	183.5872
	2419.2283	174.3588		2687.8351	183.7836
56 in.	2463.0144	175.9296	59 in.	2693.5814	183.9799
	2468.5153	176.1259		2699.3338	184.1763
	2474.0222	176.3223		2705.0924	184.3726
	2479.5354	176.5186		2710.8571	184.5690
	2485.0546	176.7150		2716.6280	184.7653
	2490.5351	176.9913		2722.4050	184.9617
	2496.1116	177.1077		2728.1882	185.1580
	2501.6493	177.3040			
	2507.1931	177.5004		2733.9774	185.3544
	2512.7431	177.6967		2739.7728	185.5507
	2518.2992	177.8931		2745.5743	185.7471
	2523.8614	178.0894		2751.8820	185.9434
	2529.4297	178.2858		2757.1957	186.1398
	2535.0043	178.4821		2763.0157	186.3361
	2540.5849	178.6785		2768.8418	186.5325
	2546.1717	178.8748		2774.6745	186.7288

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	2780.5123	186.9252	62 in.	3019.0776	194.7792
9/16	2786.3568	187.1215	1/16	3025.1675	194.9755
5/8	2792.2074	187.3179	1/8	3031.2635	195.1719
1 1/16	2798.0642	187.5142	3/16	3037.3607	195.3682
3/4	2803.9270	187.7106	1/4	3043.4740	195.5646
1 3/16	2809.7461	187.9069	5/16	3049.6885	195.7609
7/8	2815.6712	188.1033	3/8	3055.7091	195.9573
1 5/16	2821.5526	188.2996	7/16	3061.8359	196.1536
			1/2	3067.9687	196.3500
60 in.	2827.4400	188.4960	9/16	3074.1578	196.5463
1/16	2833.3336	188.6923	5/8	3080.2529	196.7427
1/8	2839.2332	188.8887	1 1/16	3086.4042	196.9390
3/16	2845.1391	189.0850	3/4	3092.5615	197.1354
1/4	2851.0510	189.2814	1 3/16	3098.7251	197.3317
5/16	2856.9692	189.4777	7/8	3104.8948	197.5281
3/8	2862.8934	189.6741	1 5/16	3111.0707	197.7244
7/16	2868.8223	189.8704			
1/2	2874.7603	189.0668	63 in.	3117.2526	197.9208
9/16	2880.7030	190.2631	1/16	3124.4407	198.1171
5/8	2886.6517	190.4595	1/8	3129.6349	198.3135
1 1/16	2892.6067	190.6558	3/16	3135.8353	198.5098
3/4	2898.5677	190.8522	1/4	3142.0417	198.7062
1 3/16	2904.5350	191.0485	5/16	3148.7544	198.9025
7/8	2910.5083	191.2449	3/8	3154.4732	199.0989
1 5/16	2916.4878	191.4412	7/16	3160.7981	199.2952
			1/2	3166.9291	199.4916
61 in.	2922.4734	191.6376	9/16	3173.1663	199.6879
1/16	2928.4652	191.8339	5/8	3179.4096	199.8843
1/8	2934.4630	192.0303	1 1/16	3185.6591	200.0806
3/16	2940.4670	192.2266	3/4	3191.9146	200.2770
1/4	2946.4771	192.4230	1 3/16	3193.1764	200.4733
5/16	2952.4938	192.6193	7/8	3204.4442	200.6697
3/8	2958.5159	192.8157	1 5/16	3210.7183	200.8660
7/16	2964.5445	193.0120			
1/2	2970.5791	193.2084	64 in.	3216.9984	201.0624
9/16	2976.6200	193.4047	1/16	3223.2847	201.2587
5/8	2982.6669	193.6011	1/8	3229.5770	201.4551
1 1/16	2988.7200	193.7974	3/16	3235.8746	201.6514
3/4	2994.7792	193.9938	1/4	3242.1782	201.8478
1 3/16	3000.8423	194.1901	5/16	3248.4936	202.0441
7/8	3006.9161	194.3865	3/8	3254.8080	202.2405
1 5/16	3017.9938	194.5828	7/16	3261.1311	202.4368

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	3267.4603	202.6332	67 in.	3525.6606	210.4872
9/16	3273.7957	202.8295	1/16	3532.2414	210.6835
5/8	3280.1372	203.0259	1/8	3538.8283	210.8799
1 1/16	3286.4875	203.2222	3/16	3545.4200	211.0762
3/4	3292.8385	203.4186	1/4	3552.0185	211.2726
1 3/16	3299.1985	203.6149	5/16	3558.6249	211.4689
7/8	3305.5645	203.8113	3/8	3565.2374	211.6653
1 5/16	3311.9367	204.0076	7/16	3571.8550	211.8616
			1/2	3578.4787	212.0580
65 in.	3318.3151	204.2040	9/16	3585.1086	212.2543
1/16	3324.7495	204.4003	5/8	3591.7446	212.4507
1/8	3331.0900	204.5917	1 1/16	3598.8868	212.6470
3/16	3337.9857	204.7930	3/4	3605.0350	212.8434
1/4	3343.8875	204.9894	1 3/16	3611.6895	213.0397
5/16	3350.2976	205.1857	7/8	3618.3500	213.2361
3/8	3356.7137	205.3821	1 5/16	3625.0168	213.4324
7/16	3363.1350	205.5784			
1/2	3369.5623	205.7748	68 in.	3631.6896	213.6288
9/16	3375.9959	205.9711	1/16	3638.3686	213.8251
5/8	3382.4355	206.1675	1/8	3645.0536	214.0215
1 1/16	3388.8813	206.3638	3/16	3651.7439	214.2178
3/4	3395.3332	206.5602	1/4	3658.4402	214.4142
1 3/16	3401.7913	206.7565	5/16	3665.1448	214.6105
7/8	3408.2555	206.9529	3/8	3671.8554	214.8069
1 5/16	3414.7259	207.1492	7/16	3678.5762	215.0032
			1/2	3685.2931	215.1996
66 in.	3421.2024	207.3456	9/16	3692.0212	215.3959
1/16	3427.6850	207.5419	5/8	3698.7554	215.5923
1/8	3434.1737	207.7383	1 1/16	3703.9957	215.7886
3/16	3440.6676	207.9346	3/4	3712.2421	215.9850
1/4	3447.1676	208.1310	1 3/16	3718.9948	216.1813
5/16	3453.6758	208.3273	7/8	3725.7535	216.3777
3/8	3468.1901	208.5237	1 5/16	3732.5184	216.5748
7/16	3470.7096	208.7200			
1/2	3473.2351	208.9164	69 in.	3739.2894	216.7704
9/16	3479.7669	209.1127	1/16	3745.8166	216.9667
5/8	3486.3047	209.3091	1/8	3752.8498	217.1631
1 1/16	3492.8487	209.5054	3/16	3759.6382	217.3594
3/4	3499.3987	209.7018	1/4	3766.4327	217.5558
1 3/16	3506.4550	209.8981	5/16	3773.2355	217.7521
7/8	3512.5174	210.0945	3/8	3780.0443	217.9485
1 5/16	3519.0860	210.2908	7/16	3786.8628	218.1448

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
½	3793.6783	218.3412	72 in.	4071.5136	226.1952
9/16	3800.5191	218.5375	1/16	4078.5853	226.3915
⅝	3807.3369	218.7339	⅛	4085.6631	226.5879
1 1/16	3814.2781	218.9302	3/16	4092.7460	226.7842
¾	3821.0200	219.1266	¼	4099.8350	226.9806
1 3/16	3827.8708	219.3229	5/16	4106.9323	227.1769
⅞	3834.7277	219.5193	⅜	4114.0356	227.3733
1 5/16	3841.5908	219.7156	7/16	4121.1442	227.5696
			½	4128.2587	227.7660
70 in.	3848.4600	219.9120	9/16	4135.3795	227.9623
1/16	3855.8353	220.1083	⅝	4142.5064	228.1587
⅛	3862.2167	220.3047	1 1/16	4149.6394	228.3550
3/16	3869.1033	220.5010	¾	4156.7785	228.5514
¼	3875.9960	220.6974	1 3/16	4163.9239	228.7477
5/16	3882.8969	220.8937	⅞	4171.0753	228.9441
⅜	3889.8039	221.0901	1 5/16	4178.2329	229.1404
7/16	3896.7211	221.2864			
½	3903.6343	221.4828	73 in.	4185.3966	229.3368
9/16	3910.5588	221.6791	1/16	4192.5665	229.5331
⅝	3917.4893	221.8755	⅛	4199.7424	229.7295
1 1/16	3924.4260	222.0718	3/16	4206.9230	229.9258
¾	3931.3687	222.2682	¼	4214.1107	230.1222
1 3/16	3938.3177	222.4645	5/16	4221.3027	230.3185
⅞	3945.2728	222.6609	⅜	4228.5077	230.5149
1 5/16	3952.2341	222.8572	7/16	4235.7109	230.7112
			½	4242.9271	230.9076
71 in.	3959.2014	223.0536	9/16	4250.1461	231.1039
1/16	3966.1749	223.2499	⅝	4257.3711	231.3003
⅛	3973.1545	223.4463	1 1/16	4264.6023	231.4966
3/16	3980.1393	223.6426	¾	4271.8396	231.6930
¼	3987.1301	223.8390	1 3/16	4279.0831	231.8893
5/16	3994.1292	224.0353	⅞	4286.3327	232.0857
⅜	4001.1344	224.2317	1 5/16	4293.5885	232.2820
7/16	4008.1447	224.4380			
½	4015.1611	224.6244	74 in.	4300.8504	232.4784
9/16	4022.1837	224.8207	1/16	4308.1185	232.6747
⅝	4029.2124	225.0171	⅛	4315.3926	232.8711
1 1/16	4036.2473	225.2134	3/16	4322.1719	233.0674
¾	4043.2882	225.4098	¼	4329.9572	233.2638
1 3/16	4050.3354	225.6061	5/16	4337.2508	233.4601
⅞	4057.3886	225.8025	⅜	4344.5505	233.6565
1 5/16	4064.4481	225.9988	7/16	4351.8551	233.8528

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	4359.1663	234.0492	77 in.	4656.6366	241.9032
9/16	4366.4835	234.2455	1/16	4664.1992	242.0995
1/8	4373.8067	234.4419	1/8	4671.7678	242.2959
1/16	4381.1361	234.6382	3/16	4679.3416	242.4922
3/4	4388.4715	234.8346	1/4	4686.9215	242.6886
1 3/16	4396.3132	235.0309	5/16	4694.5097	242.8849
7/8	4403.1610	235.2273	3/8	4702.1039	243.0813
1 5/16	4410.5150	235.4236	7/16	4709.7033	243.2776
			1/2	4717.3087	243.4740
75 in.	4417.8750	235.6200	9/16	4724.9204	243.6703
1/16	4425.2412	235.8163	5/8	4732.5381	243.8667
1/8	4432.6135	236.0127	1 1/16	4740.1620	244.0630
3/16	4439.9910	236.2090	3/4	4747.7920	244.2594
1/4	4447.3745	236.4054	1 3/16	4755.8782	244.4557
5/16	4454.7663	236.6017	7/8	4763.0705	244.6521
3/8	4462.1642	236.7981	1 5/16	4771.1690	244.8484
7/16	4469.5672	236.9944			
1/2	4476.9763	237.1908	78 in.	4778.3736	245.0448
9/16	4484.3916	237.3871	1/16	4786.0344	245.2411
5/8	4491.8130	237.5835	1/8	4793.7012	245.4375
1 1/16	4499.2406	237.7798	3/16	4801.3732	245.6338
3/4	4506.6742	237.9762	1/4	4809.0512	245.8302
1 3/16	4514.1141	238.1725	5/16	4817.1375	246.0265
7/8	4521.5600	238.3689	3/8	4824.4299	246.2229
1 5/16	4528.9622	238.5652	7/16	4832.1275	246.4192
			1/2	4839.8311	246.6156
76 in.	4536.4704	238.7616	9/16	4847.5409	246.8119
1/16	4543.9333	238.9579	5/8	4855.2568	247.0083
1/8	4551.4023	239.1543	1 1/16	4862.9789	247.2046
3/16	4558.8794	239.3506	3/4	4870.7071	247.4010
1/4	4566.3626	239.5470	1 3/16	4878.4415	247.5973
5/16	4573.8526	239.7433	7/8	4886.1820	247.7937
3/8	4581.3486	239.9397	1 5/16	4893.9287	247.9900
7/16	4588.8493	240.1360			
1/2	4596.3571	240.3324	79 in.	4901.6814	248.1864
9/16	4603.8706	240.5287	1/16	4909.4403	248.3827
5/8	4611.3902	240.7251	1/8	4917.2053	248.5791
1 1/16	4618.9159	240.9214	3/16	4924.9755	248.7754
3/4	4626.4477	241.1178	1/4	4932.7517	248.9718
1 3/16	4633.9858	241.3141	5/16	4940.5362	249.1681
7/8	4641.5299	241.5105	3/8	4948.3268	249.3645
1 5/16	4649.0802	241.7068	7/16	4956.1225	249.5608

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	4963.9243	249.7572	82 in.	5281.0296	257.6112
1 9/16	4971.7319	249.9535	1/16	5289.0781	257.8075
2/8	4979.5456	250.1499	1/8	5297.1426	258.0039
1 1/16	4987.3663	250.3462	1 3/16	5305.2073	258.2002
3/4	4995.1930	250.5426	1/4	5313.2780	258.3966
1 3/16	5003.0316	250.7389	1 5/16	5321.3570	258.5929
7/8	5010.8642	250.9353	3/8	5329.4421	258.7893
1 5/16	5018.7091	251.1316	1 7/16	5337.5324	258.9856
			1/2	5345.6287	259.1820
80 in.	5026.5600	251.3280	1 9/16	5353.7809	259.3783
1/16	5034.4171	251.5243	2/8	5361.8391	259.5747
1/8	5042.2803	251.7207	1 1/16	5369.9543	259.7710
1 3/16	5050.1486	251.9170	3/4	5378.0755	259.9674
1/4	5058.0230	252.1134	1 3/16	5386.2026	260.1637
1 5/16	5065.9027	252.3097	7/8	5394.3358	260.3601
3/8	5073.7944	252.5061	1 5/16	5402.4552	260.5564
1 7/16	5081.6883	252.7024			
1/2	5089.5883	252.8988	83 in.	5410.6206	260.7528
1 9/16	5097.4941	253.0951	1/16	5418.7722	260.9491
2/8	5105.4060	253.2915	1/8	5426.9299	261.1455
1 1/16	5113.8248	253.4878	1 3/16	5435.0928	261.3418
3/4	5121.2497	253.6842	1/4	5443.2617	261.5382
1 3/16	5129.1855	253.8805	1 5/16	5451.4389	261.7345
7/8	5137.1173	254.0769	3/8	5459.6222	261.9309
1 5/16	5145.0603	254.2732	1 7/16	5467.8106	262.1272
			1/2	5476.0051	262.3236
81 in.	5153.0094	254.4696	1 9/16	5484.2054	262.5199
1/16	5160.9647	254.6659	2/8	5492.4118	262.7163
1/8	5168.9260	254.8623	1 1/16	5500.6252	262.9126
1 3/16	5176.8925	255.0586	3/4	5508.8446	263.1090
1/4	5184.8651	255.2550	1 3/16	5517.0699	263.3053
1 5/16	5192.8460	255.4513	7/8	5525.3012	263.5017
3/8	5200.8329	255.6477	1 5/16	5533.5388	263.6980
1 7/16	5208.8250	255.8440			
1/2	5216.8231	256.0404	84 in.	5541.7824	263.8944
1 9/16	5224.8271	256.2367	1/16	5550.0322	264.0907
2/8	5232.8371	256.4331	1/8	5558.2881	264.2871
1 1/16	5240.8568	256.6294	1 3/16	5566.5491	264.4834
3/4	5248.8772	256.8258	1/4	5574.8162	264.6798
1 3/16	5256.9061	257.0221	1 5/16	5583.0916	264.8761
7/8	5264.9411	257.2105	3/8	5591.3730	265.0725
1 5/16	5272.9828	257.4148	1 7/16	5599.6596	265.2688

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	5607.9523	265.4652	87 in.	5944.6926	273.3192
9/16	5616.2508	265.6615	1/16	5953.2369	273.5155
5/8	5624.5554	265.8579	1/8	5961.7873	273.7119
1 1/16	5632.8662	266.0542	3/16	5970.3429	273.9082
3/4	5641.1845	266.2506	1/4	5978.9045	274.1046
1 3/16	5649.5071	266.4469	5/16	5987.4749	274.3009
7/8	5657.8357	266.6433	3/8	5996.0504	274.4973
1 5/16	5666.1723	266.8396	7/16	6004.6315	274.6936
			1/2	6013.2187	274.8900
85 in.	5674.5150	267.0360	9/16	6021.8117	275.0863
1/16	5682.8630	267.2323	5/8	6030.4108	275.2827
1/8	5691.2170	267.4287	1 1/16	6039.0169	275.4790
3/16	5699.5762	267.6250	3/4	6047.6290	275.6754
1/4	5707.9415	267.8214	1 3/16	6056.2470	275.8717
5/16	5716.3151	268.0177	7/8	6064.8710	276.0681
3/8	5724.6947	268.2141	1 5/16	6073.5013	276.2644
7/16	5733.0795	268.4104			
1/2	5741.4703	268.6068	88 in.	6082.1376	276.4608
9/16	5749.8670	268.8031	1/16	6090.7801	276.6671
5/8	5758.2697	268.9997	1/8	6099.4287	276.8535
1 1/16	5766.6794	269.1958	3/16	6108.0824	277.0498
3/4	5775.0952	269.3922	1/4	6116.7422	277.2462
1 3/16	5783.5168	269.5885	5/16	6125.4103	277.4425
7/8	5791.9445	269.7849	3/8	6134.0844	277.6389
1 5/16	5800.3784	269.9812	7/16	6144.2637	277.8352
			1/2	6151.4491	278.0316
86 in.	5808 8184	270.1776	9/16	6160.1403	278.2279
1/16	5817.2651	270.3739	5/8	6169.8376	278.4243
1/8	5825.7168	270.5703	1 1/16	6177.5418	278.6206
3/16	5834.1742	270.7666	3/4	6186.2521	278.8170
1/4	5842.6376	270.9630	1 3/16	6194.9683	279.0133
5/16	5851.1093	271.1593	7/8	6203.6905	279.2097
3/8	5859.5871	271.3557	1 5/16	6212.4189	279.4060
7/16	5868.0701	271.5520			
1/2	5876.5591	271.7484	89 in.	6221.1534	279.6024
9/16	5885.0540	271.9447	1/16	6229.8941	279.7987
5/8	5893.5549	272.1411	1/8	6238.6408	279.9951
1 1/16	5902.0620	272.3374	3/16	6247.3927	280.1914
3/4	5910.5767	272.5338	1/4	6256.1507	280.3878
1 3/16	5919.0965	272.7301	5/16	6264.9170	280.5841
7/8	5927.6224	272.9265	3/8	6273.6893	280.7805
1 5/16	5936.1545	273.1228	7/16	6282.4668	280.9768

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	6291.2503	281.1732	92 in.	6647.6258	289.0272
1 9/16	6300.0397	281.3695	1 1/16	6656.6609	289.2235
5/8	6308.8351	281.5659	1/8	6665.7021	289 4199
1 11/16	6317.6375	281.7622	1 3/16	6674.7485	289.6162
3/4	6326.4460	281.9586	1/4	6683.8010	289.8125
1 13/16	6335.2603	282.1549	1 5/16	6692.8618	290.0089
7/8	6344.0807	282.3513	3/8	6701.9286	290.2053
1 15/16	6352.9073	282.5476	1 7/16	6711.5001	290.4016
			1/2	6720.0787	290.5980
90 in.	6361.7400	282.7440	1 9/16	6729.6628	290.7943
1 1/16	6370.5789	282.9403	5/8	6738.2530	290.9907
1/8	6379.4238	283.1367	1 11/16	6747.3497	291.1870
1 3/16	6388.7739	283.3330	3/4	6756.4525	291.3834
1/4	6397.1300	283.5294	1 13/16	6765.5614	291.5797
1 5/16	6405.9944	283.7257	7/8	6774.6763	291.7761
3/8	6414.8649	283.9221	1 15/16	6783.7975	291.9724
1 7/16	6423.7906	284.1184			
1/2	6432.6223	284.3148	93 in.	6792.9248	292.1688
1 9/16	6441.5101	284.5111	1 1/16	6802.0581	292.3651
5/8	6450.4039	284.7075	1/8	6811.1974	292.5615
1 11/16	6459.3043	284.9038	1 3/16	6820.3420	292.7578
3/4	6468.2107	285.1002	1/4	6829.4927	292.9542
1 13/16	6477.1232	285.2965	1 5/16	6838.6517	293.1505
7/8	6486.0418	285.4929	3/8	6847.8167	293.3469
1 15/16	6494.9566	285.6892	1 7/16	6856.9869	293.5432
			1/2	6866.1631	293.7396
91 in.	6503.8974	285.8856	1 9/16	6875.3454	293.9359
1 1/16	6512.8344	286.0819	5/8	6884.5338	294.1323
1/8	6521.7775	286.2783	1 11/16	6893.7337	294.3286
1 3/16	6530.7258	286.4746	3/4	6902.9296	294.5250
1/4	6539.6801	286.6710	1 13/16	6912.1366	294.7213
1 5/16	6548.6427	286.8673	7/8	6921.3497	294.9177
3/8	6557.6114	287.0637	1 15/16	6930.5691	295.1140
1 7/16	6566.5857	287.2600			
1/2	6573.5651	287.4564	94 in.	6939.7946	295.3104
1 9/16	6584.5511	287.6527	1 1/16	6949.5261	295.5067
5/8	6593.5431	287.8491	1/8	6958.2636	295.7031
1 11/16	6602.5443	288.0454	1 3/16	6968.0064	295.8994
3/4	6611.5462	288.2418	1/4	6976.7552	296.0958
1 13/16	6620.5569	288.4381	1 5/16	6986.0123	296.2921
7/8	6629.5736	288.6345	3/8	6995.2755	296.4885
1 15/16	6638.5967	288.8388	1 7/16	7004.5439	296.6848

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	7013.8183	296.8812	97 in.	7389.8288	304.7352
9/16	7023.0988	297.0775	1/16	7399.3548	304.9315
5/8	7032.3853	297.2739	1/8	7408.8868	305.1279
1 1/16	7041.6784	297.4702	3/16	7418.6241	305.3242
3/4	7050.9775	297.6666	1/4	7427.9675	305 5206
1 3/16	7060.2827	297.8629	5/16	7437.5192	305.7169
7/8	7069.5940	298.0593	3/8	7447.0769	305.9133
1 5/16	7075.9116	298.2556	7/16	7456.6398	306.1096
			1/2	7466.2087	306.3060
95 in.	7088.2352	298.4520	9/16	7475.7837	306.5023
1/16	7097.5738	298.6483	5/8	7485.3648	306.6987
1/8	7106.9005	298.8447	1 1/16	7494.9524	306.8950
3/16	7116.7415	299.0400	3/4	7504.5460	307 0914
1/4	7125.5885	299.2374	1 3/16	7514.1457	307.2877
5/16	7134.9443	299.4337	7/8	7523.7515	307.4841
3/8	7144.3052	299.6301	1 5/16	7533.3636	307.6804
7/16	7153.6717	299.8264			
1/2	7163.0443	300.0228	98 in.	7542.9818	307.8768
9/16	7172.4230	300.2191	1/16	7552.6060	308.0731
5/8	7181.8077	300.4155	1/8	7562.2362	308.2695
1 1/16	7191.1989	300.6118	3/16	7575.8717	308.4658
3/4	7200.5962	300.8082	1/4	7581.5132	308.6622
1 3/16	7209.9096	301.0045	5/16	7591.1630	308.8585
7/8	7219.4090	301.2009	3/8	7600.8189	309.0549
1 5/16	7228.8248	301.3972	7/16	7610.4800	309.2512
			1/2	7620.1471	309.4476
96 in.	7238.2466	301.5936	9/16	7629.8203	309.6439
1/16	7247.6741	301.7899	5/8	7639.4995	309.8403
1/8	7257.1083	301.9863	1 1/16	7649.1853	310.0366
3/16	7266.5474	302.1826	3/4	7658.8771	310.2330
1/4	7275.9926	302.3790	1 3/16	7668.5750	310.4293
5/16	7285.4461	302.5753	7/8	7678.2790	310.6257
3/8	7294.9056	302.7717	1 5/16	7687.9893	310.8220
7/16	7304.3703	302.9680			
1/2	7313.8411	303.1644	99 in.	7697.7056	311.0184
9/16	7323.3179	303.3607	1/16	7707.4279	311.2147
5/8	7332.8008	303.5571	1/8	7717.1563	311.4111
1 1/16	7342.2902	303.7534	3/16	7726.8900	311.6074
3/4	7351.7857	303.9498	1/4	7736.6297	311.8038
1 3/16	7361.2873	304.1461	5/16	7746.3777	312.0001
7/8	7370.7949	304.3425	3/8	7756.1318	312.1965
1 5/16	7380.3088	304.5388	7/16	7765.8910	312.3928

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
½	7775.6563	312.5892	½	8413.4008	325.1556
9/16	7785.4277	312.7855	¾	8454.0944	325.9410
⅝	7795.2051	312.9819			
11/16	7804.9890	313.0782	104 in.	8494.8864	326.7264
¾	7814.7790	313.3746	¼	8535.7760	327.5118
13/16	7824.5751	313.5709	½	8576.7640	328.2972
7/8	7834.3772	313.7673	¾	8617.8504	329.0826
15/16	7844.1856	313.9636			
			105 in.	8659.0348	329.8680
100 in.	7854.0000	314.1600	¼	8700.3176	330.6534
¼	7893.3190	314.9454	½	8741.6980	331.4388
½	7932.7360	315.7308	¾	8783.1772	332.2242
¾	7972.2120	316.5162			
			106 in.	8824.7544	333.0096
101 in.	8011.8652	317.3016	½	8908.2028	334.5804
¼	8051.5772	318.0870			
½	8091.3870	318.8724	107 in.	8992.0444	336.1512
¾	8131.2953	319.6578	½	9076.2784	337.7220
102 in.	8171.3016	320.4432	108 in.	9160.9056	339.2928
¼	8211.4060	321.2286	½	9245.9248	340.8636
½	8251.6084	322.0140			
¾	8291.8696	322.7994	109 in.	9331.3372	342.4344
			½	9417.1420	344.0052
103 in.	8332.3085	323.5848			
¼	8372.8056	324.3702	110 in.	9503.3400	345.5760

A Table of Diameters, Areas, and Circumferences of Circles, in Feet, from 1 to 50 Feet.

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
1 ft.	.7854	3 1⅝	2	13.6353	13 1
1	.9217	3 4⅝	3	14.1862	13 4⅛
2	1.0690	3 8	4	14.7479	13 7¼
3	1.2271	3 11	5	15.3206	13 10½
4	1.3962	4 2⅛	6	15.9043	14 1⅝
5	.5761	4 5⅜	7	16.4986	14 4⅝
6	1.7671	4 8⅓	8	17.1041	14 7⅞
7	1.9689	4 11⅝	9	17.7205	14 11
8	2.1816	5 2¾	10	18.3476	15 2⅛
9	2.4052	5 5⅞	11	18.9858	15 5¼
10	2.6398	5 9	5 ft.	19.6350	15 8½
11	2.8852	6 2¼	1	20.2947	15 11⅝
2 ft.	3.1416	6 3⅜	2	20.9656	16 2¾
1	3.4087	6 6½	3	21.6475	16 5¾
2	3.6869	6 9⅝	4	22.3400	16 9
3	3.9760	7 0¾	5	23.0437	17 0⅛
4	4.2760	7 3⅞	6	23.7583	17 3¼
5	4.5869	7 7	7	24.4835	17 6⅜
6	4.9087	7 10¼	8	25.2199	17 9⅝
7	5.2413	8 1⅜	9	25.9672	18 0¾
8	5.5850	8 4½	10	26.7251	18 3⅞
9	5.9395	8 7⅝	11	27.4943	18 7⅛
10	6.3049	8 10¾	6 ft.	28.2744	18 10⅛
11	6.6813	9 1⅞	1	29.0649	19 1¼
3 ft.	7.0686	9 5	2	29.8668	19 4⅜
1	7.4666	9 8¼	3	30.6796	19 7½
2	7.8757	9 11⅜	4	31.5029	19 10⅝
3	8.2957	10 2½	5	32.3376	20 1⅞
4	8.7265	10 5⅝	6	33.1831	20 4⅞
5	9.1683	10 8¾	7	34.0391	20 8⅛
6	9.6211	10 11⅞	8	34.9065	20 11½
7	10.0846	11 3	9	35.7847	21 2⅜
8	10.5591	11 6⅛	10	36.6735	21 5½
9	11.0446	11 9⅜	11	37.5736	21 8¾
10	11.5409	12 0½	7 ft.	38.4846	21 11⅞
11	12.0481	12 3⅝	1	39.4060	22 3
4 ft.	12.5664	12 6¾	2	40.3388	22 6⅛
1	13.0952	12 9⅞	3	41.2825	22 9¼

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.
4	42.2367	23 $0\frac{3}{8}$	6	86.5903	32 $11\frac{3}{4}$
5	43.2022	23 $2\frac{1}{8}$	7	87.9697	33 $2\frac{7}{8}$
6	44.1787	23 $6\frac{3}{4}$	8	89.3608	33 $6\frac{1}{8}$
7	45.1656	23 11	9	90.7627	33 $9\frac{1}{4}$
8	46.1638	24 $1\frac{1}{8}$	10	92.1749	34 $0\frac{3}{8}$
9	47.1730	24 $4\frac{1}{8}$	11	93.5986	34 $3\frac{1}{2}$
10	48.1926	24 $7\frac{1}{4}$	11 ft.	95.0334	34 $6\frac{5}{8}$
11	49.2236	24 $10\frac{3}{8}$	1	96.4783	34 $9\frac{3}{4}$
8 ft.	50.2656	25 $1\frac{1}{2}$	2	97.9347	35 $0\frac{7}{8}$
1	51.3178	25 $4\frac{5}{8}$	3	99.4021	35 $4\frac{1}{8}$
2	52.3816	25 $7\frac{7}{8}$	4	100.8797	35 $7\frac{1}{4}$
3	53.4562	25 11	5	102.3689	35 $10\frac{3}{8}$
4	54.5412	26 $2\frac{1}{8}$	6	103.8691	36 $1\frac{1}{2}$
5	55.6377	26 $5\frac{1}{4}$	7	105.3794	36 $4\frac{5}{8}$
6	56.7451	26 $8\frac{3}{8}$	8	106.9013	36 $7\frac{3}{4}$
7	57.8628	26 $11\frac{1}{2}$	9	108.4342	36 $10\frac{7}{8}$
8	58.9920	27 $2\frac{3}{4}$	10	109.9772	37 $2\frac{3}{4}$
9	60.1321	27 $5\frac{3}{4}$	11	111.5319	37 $5\frac{1}{4}$
10	61.2826	27 9	12 ft.	113.0976	37 $8\frac{3}{8}$
11	62.4445	28 $0\frac{1}{8}$	1	114.6732	37 $11\frac{1}{2}$
9 ft.	63.6174	28 $3\frac{1}{4}$	2	116.2607	38 $2\frac{5}{8}$
1	64.8006	28 $6\frac{3}{8}$	3	117.8590	38 $5\frac{3}{4}$
2	65.9951	28 $9\frac{1}{2}$	4	119.4674	38 $8\frac{7}{8}$
3	67.2007	29 $0\frac{5}{8}$	5	121.0876	39 0
4	68.4166	29 $3\frac{3}{4}$	6	122.7187	39 $3\frac{1}{4}$
5	69.6440	29 7	7	124.3598	39 $6\frac{3}{8}$
6	70.8823	29 $10\frac{1}{8}$	8	126.0127	39 $9\frac{1}{2}$
7	72.1309	30 $1\frac{1}{4}$	9	127.6765	40 $0\frac{5}{8}$
8	73.3910	30 $4\frac{3}{8}$	10	129.3504	40 $3\frac{3}{4}$
9	74.6620	30 $7\frac{1}{2}$	11	131.0360	40 $6\frac{7}{8}$
10	75.9433	30 $11\frac{5}{8}$	13 ft.	132.7326	40 10
11	77.2362	31 $1\frac{3}{4}$	1	134.4391	41 $1\frac{1}{8}$
10 ft.	78.5400	31 5	2	136.1574	41 $4\frac{3}{8}$
1	79.8540	31 $8\frac{1}{8}$	3	137.8867	41 $7\frac{1}{2}$
2	81.1795	31 $11\frac{1}{4}$	4	139.6260	41 $10\frac{5}{8}$
3	82.5160	32 $2\frac{3}{8}$	5	141.3771	42 $1\frac{3}{4}$
4	83.8627	32 $5\frac{1}{2}$	6	143.1391	42 $4\frac{7}{8}$
5	85.2211	32 $8\frac{5}{8}$	7	144.9111	42 8

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
8	146.6949	42 $11\frac{1}{8}$	10	222.5510	52 $10\frac{1}{2}$
9	148.4896	43 $2\frac{1}{4}$	11	224.7603	53 $1\frac{5}{8}$
10	150.2943	43 $5\frac{1}{2}$	17 ft.	226.9806	53 $4\frac{7}{8}$
11	152.1109	43 $8\frac{5}{8}$	1	229.2105	53 8
14 ft.	153.9384	43 $11\frac{3}{4}$	2	231.4525	53 $11\frac{1}{8}$
1	155.7758	44 $2\frac{7}{8}$	3	233.7055	54 $2\frac{1}{4}$
2	157.6250	44 6	4	235.9682	54 $5\frac{3}{8}$
3	159.4852	44 $9\frac{1}{8}$	5	238.2430	54 $8\frac{1}{2}$
4	161.3553	45 $0\frac{1}{4}$	6	240.5287	54 $11\frac{5}{8}$
5	163.2373	45 $3\frac{1}{2}$	7	242.8241	55 $2\frac{7}{8}$
6	165.1303	45 $6\frac{5}{8}$	8	245.1316	55 6
7	167.0331	45 $9\frac{3}{4}$	9	247.4500	55 $9\frac{1}{8}$
8	168.9479	46 $0\frac{7}{8}$	10	249.7781	56 $0\frac{1}{4}$
9	170.8735	46 4	11	252.1184	56 $3\frac{1}{2}$
10	172.8091	46 $7\frac{1}{8}$	18 ft.	254.4696	56 $6\frac{5}{8}$
11	174.7565	46 $11\frac{1}{4}$	1	256.8303	56 $9\frac{5}{8}$
15 ft.	176.7150	47 $1\frac{1}{2}$	2	259.2033	57 $0\frac{7}{8}$
1	178.6832	47 $4\frac{5}{8}$	3	261.5872	57 4
2	180.6634	47 $7\frac{3}{4}$	4	263.9807	57 $7\frac{1}{8}$
3	182.6545	47 $10\frac{7}{8}$	5	266.3864	57 $10\frac{1}{4}$
4	184.6555	48 $2\frac{1}{2}$	6	268.8031	58 $1\frac{3}{8}$
5	186.6684	48 $5\frac{1}{8}$	7	271.2293	58 $4\frac{1}{2}$
6	188.6923	48 $8\frac{1}{4}$	8	273.6678	58 $7\frac{5}{8}$
7	190.7260	48 $11\frac{3}{8}$	9	276.1171	58 $10\frac{3}{4}$
8	192.7716	49 $2\frac{5}{8}$	10	278.5761	59 2
9	194.8282	49 $5\frac{3}{4}$	11	281.0472	59 $5\frac{1}{8}$
10	196.8946	49 $8\frac{7}{8}$	19 ft.	283.5294	59 $8\frac{1}{4}$
11	198.9730	50 0	1	286.0210	59 $11\frac{1}{2}$
16 ft.	201.0624	50 $3\frac{1}{8}$	2	288.5249	60 $2\frac{1}{2}$
1	203.1615	50 $6\frac{1}{4}$	3	291.0397	60 $5\frac{5}{8}$
2	205.2726	50 $9\frac{5}{8}$	4	293.5641	60 $8\frac{3}{4}$
3	207.3946	51 $0\frac{1}{2}$	5	296.1107	60 $11\frac{7}{8}$
4	209.5264	51 $3\frac{3}{4}$	6	298.6483	61 $3\frac{1}{8}$
5	211.6703	51 $6\frac{1}{2}$	7	301.2054	61 $6\frac{1}{4}$
6	213.8251	51 10	8	303.7747	61 $9\frac{1}{4}$
7	215.9896	52 $1\frac{1}{8}$	9	306.3550	62 $0\frac{1}{2}$
8	218.1662	52 $4\frac{1}{4}$	10	308.9448	62 $3\frac{5}{8}$
9	220.3537	52 $7\frac{3}{8}$	11	311.5469	62 $6\frac{3}{4}$

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
20 ft.	314.1600	62 9⅞	2	421.5192	72 9⅜
1	316.7824	63 1⅛	3	424.5577	73 0½
2	319.4173	63 4¼	4	427.6055	73 3⅝
3	322.0630	63 7⅜	5	430.6658	73 6¾
4	324.7182	63 11½	6	433.7371	73 9⅞
5	327.3858	64 1⅝	7	436.8175	74 1
6	330.0643	64 4¾	8	439.9106	74 4⅛
7	332.7522	64 7⅞	9	443.0146	74 7¼
8	335.4525	64 11	10	446.1278	74 10⅜
9	338.1637	65 2¼	11	449.2536	75 1⅝
10	340.8844	65 5⅜	24 ft.	452.3904	75 4¾
11	343.6174	65 8¼	1	455.5362	75 7⅞
21 ft.	346.3614	65 11⅜	2	458.6948	75 11
1	349.1147	66 2¾	3	461.8642	76 2⅛
2	351.8804	66 5⅛	4	465.0428	76 5¼
3	354.6571	66 9	5	468.2341	76 8½
4	357.4432	67 0¼	6	471.4363	76 11⅝
5	360.2417	67 3⅜	7	474.6476	77 2¾
6	363.0511	67 6½	8	477.8716	77 5⅞
7	365.8698	67 9⅝	9	481.1065	77 9
8	368.7011	68 0¼	10	484.3506	78 0⅛
9	371.5432	68 3⅞	11	487.6073	78 3¼
10	374.3947	68 7	25 ft.	490.8750	78 6⅜
11	377.2587	68 10¼	1	494.1516	78 9½
22 ft.	380.1336	69 1⅜	2	497.4411	79 0¾
1	383.0177	69 4½	3	500.7415	79 3⅞
2	385.9144	69 7⅝	4	504.0510	79 7⅛
3	388.8220	69 10¾	5	507.3732	79 11⅛
4	391.7389	70 1⅞	6	510.7063	80 1¼
5	394.6683	70 5	7	514.0484	80 4⅜
6	397.6087	70 8¼	8	517.4034	80 7⅝
7	400.5583	70 11⅛	9	520.7692	80 10¾
8	403.5204	71 2½	10	524.1441	81 1⅛
9	406.4935	71 5⅝	11	527.5318	81 5
10	409.4759	71 8¾	26 ft.	530.9304	81 8⅛
11	412.4707	71 11⅞	1	534.3379	81 11¼
23 ft.	415.4766	72 3	2	537.7583	82 2⅜
1	418.4915	72 6⅛	3	541.1896	82 5¼

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
4	544.6299	82 $8\frac{5}{8}$	6	683.4943	92 $8\frac{1}{8}$
5	548.0830	82 $11\frac{7}{8}$	7	687.3598	92 $11\frac{1}{8}$
6	551.5471	83 3	8	691.2385	93 $2\frac{3}{8}$
7	555.0201	83 $6\frac{1}{8}$	9	695.1280	93 $5\frac{1}{2}$
8	558.5059	83 $9\frac{1}{4}$	10	699.0263	93 $8\frac{5}{8}$
9	562.0027	84 $0\frac{3}{8}$	11	702.9377	93 $11\frac{7}{8}$
10	565.5084	84 $3\frac{1}{2}$	30 ft.	706.8600	94 $2\frac{7}{8}$
11	569.0270	84 $6\frac{5}{8}$	1	710.7909	94 6
27 ft.	572.5566	84 $9\frac{7}{8}$	2	714.7350	94 $9\frac{1}{4}$
1	576.0949	85 1	3	718.6900	95 $0\frac{3}{8}$
2	579.6463	85 $4\frac{1}{4}$	4	722.6537	95 $3\frac{1}{2}$
3	583.2085	85 $8\frac{1}{8}$	5	726.6305	95 $6\frac{5}{8}$
4	586.7796	85 $11\frac{3}{8}$	6	730.6183	95 $9\frac{3}{4}$
5	590.3637	86 $1\frac{1}{2}$	7	734.6147	96 $0\frac{7}{8}$
6	593.9587	86 $4\frac{5}{8}$	8	738.6242	96 4
7	597.5625	86 $7\frac{7}{8}$	9	742.6447	96 $7\frac{1}{4}$
8	601.1793	86 11	10	746.6738	96 $10\frac{3}{8}$
9	604.8070	87 $2\frac{1}{8}$	11	750.7161	97 $1\frac{1}{2}$
10	608.4436	87 $5\frac{1}{4}$	31 ft.	754.7694	97 $4\frac{5}{8}$
11	612.0931	87 $8\frac{3}{8}$	1	758.8311	97 $7\frac{3}{4}$
28 ft.	615.7536	87 $11\frac{1}{2}$	2	762.9062	97 $10\frac{7}{8}$
1	619.4228	88 $2\frac{5}{8}$	3	766.9921	98 2
2	623.1050	88 $5\frac{3}{4}$	4	771.0866	98 $5\frac{1}{8}$
3	626.7982	88 9	5	775.1944	98 $8\frac{3}{8}$
4	630.5002	89 $0\frac{1}{8}$	6	779.3131	98 $11\frac{1}{2}$
5	634.2152	89 $3\frac{1}{4}$	7	783.4403	99 $2\frac{5}{8}$
6	637.9411	89 $6\frac{3}{8}$	8	787.5808	99 $5\frac{3}{4}$
7	641.6758	89 $9\frac{1}{2}$	9	791.7322	99 $8\frac{7}{8}$
8	645.4235	90 $0\frac{5}{8}$	10	795.8922	100 0
9	649.1821	90 $3\frac{3}{4}$	11	800.0654	100 $3\frac{1}{8}$
10	652.9495	90 $6\frac{7}{8}$	32 ft.	804.2496	100 $6\frac{3}{8}$
11	656.7300	90 $11\frac{1}{8}$	1	808.4422	100 $9\frac{1}{2}$
29 ft.	660.5214	91 $1\frac{1}{4}$	2	812.6481	101 $0\frac{5}{8}$
1	664.3214	91 $4\frac{3}{8}$	3	816.8650	101 $3\frac{3}{4}$
2	668.1346	91 $7\frac{1}{2}$	4	821.0904	101 $6\frac{7}{8}$
3	671.9587	91 $10\frac{5}{8}$	5	825.3291	101 10
4	675.7915	92 $1\frac{3}{4}$	6	829.5787	102 $1\frac{1}{8}$
5	679.6375	92 $4\frac{7}{8}$	7	833.8368	102 $4\frac{3}{8}$

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
8	838.1082	102 $7\frac{1}{2}$	10	1008.4736	112 $6\frac{7}{8}$
9	842.3905	102 $10\frac{5}{8}$	11	1013.1705	112 10
10	846.6813	103 $1\frac{3}{4}$	36 ft.	1017.8784	113 $1\frac{1}{8}$
11	850.9855	103 $4\frac{7}{8}$	1	1022.5944	113 $4\frac{1}{4}$
33 ft.	855.3006	103 8	2	1027.3240	113 $7\frac{3}{8}$
1	859.6240	103 $11\frac{1}{8}$	3	1032.0646	113 $10\frac{5}{8}$
2	863.9609	104 $2\frac{1}{4}$	4	1036.8134	114 $1\frac{3}{4}$
3	868.3087	104 $5\frac{3}{8}$	5	1041.5758	114 $4\frac{7}{8}$
4	872.6649	104 $8\frac{5}{8}$	6	1046.3491	114 8
5	877.0346	104 $11\frac{3}{4}$	7	1051.1306	114 $11\frac{1}{8}$
6	881.4151	105 $2\frac{7}{8}$	8	1055.9257	115 $2\frac{1}{4}$
7	885.8040	105 6	9	1060.7317	115 $5\frac{3}{8}$
8	890.2064	105 $9\frac{1}{8}$	10	1065.5459	115 $9\frac{1}{4}$
9	894.6196	106 $0\frac{1}{4}$	11	1070.3738	115 $11\frac{5}{8}$
10	899.0413	106 $3\frac{3}{8}$	37 ft.	1075.2126	116 $2\frac{7}{8}$
11	903.4763	106 $6\frac{5}{8}$	1	1080.0594	116 6
34 ft.	907.9224	106 $9\frac{3}{4}$	2	1084.9201	116 $9\frac{1}{8}$
1	912.3767	107 $0\frac{7}{8}$	3	1089.7915	117 $0\frac{1}{4}$
2	916.8445	107 4	4	1094.6711	117 $3\frac{1}{2}$
3	921.3232	107 $7\frac{1}{8}$	5	1099.5644	117 $6\frac{1}{2}$
4	925.8103	107 $10\frac{1}{4}$	6	1104.4687	117 $9\frac{5}{8}$
5	930.3108	108 $1\frac{3}{8}$	7	1109.3810	118 $0\frac{3}{4}$
6	934.8223	108 $4\frac{5}{8}$	8	1114.3071	118 4
7	939.3421	108 $7\frac{3}{4}$	9	1119.2440	118 $7\frac{1}{8}$
8	943.8753	108 $10\frac{7}{8}$	10	1124.1891	118 $10\frac{1}{4}$
9	948.4195	109 2	11	1129.1478	119 $1\frac{3}{8}$
10	952.9720	109 $5\frac{1}{8}$	38 ft.	1134.1176	119 $4\frac{1}{2}$
11	957.5380	109 $8\frac{1}{4}$	1	1139.0953	119 $7\frac{5}{8}$
35 ft.	962.1150	109 $11\frac{3}{8}$	2	1144.0868	119 $10\frac{3}{4}$
1	966.7001	110 $2\frac{3}{8}$	3	1149.0892	120 2
2	971.2989	110 $5\frac{3}{4}$	4	1154.0997	120 $5\frac{1}{8}$
3	975.9085	110 $8\frac{7}{8}$	5	1159.1239	120 $8\frac{3}{8}$
4	980.5264	111 0	6	1164.1591	120 $11\frac{3}{8}$
5	985.1579	111 $3\frac{1}{8}$	7	1169.2023	121 $2\frac{1}{2}$
6	989.8003	111 $6\frac{1}{4}$	8	1174.2592	121 $5\frac{5}{8}$
7	994.4509	111 $9\frac{3}{8}$	9	1179.3271	121 $8\frac{3}{4}$
8	999.1151	112 $0\frac{1}{2}$	10	1184.4030	121 $11\frac{7}{8}$
9	1003.7902	112 $3\frac{3}{4}$	11	1189.4927	122 $3\frac{1}{8}$

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
39 ft.	1194.5934	122 $6\frac{1}{4}$	2	1396.4619	132 $5\frac{5}{8}$
1	1199.7195	122 $9\frac{1}{2}$	3	1401.9880	132 $8\frac{3}{4}$
2	1204.8244	123 $0\frac{7}{8}$	4	1407.5219	132 $11\frac{7}{8}$
3	1209.9577	123 $3\frac{5}{8}$	5	1413.0698	133 3
4	1215.0990	123 $6\frac{3}{4}$	6	1418.6287	133 $6\frac{1}{8}$
5	1220.2542	123 $9\frac{7}{8}$	7	1424.1952	133 $9\frac{1}{4}$
6	1225.4203	124 $1\frac{1}{8}$	8	1429.7759	134 $0\frac{1}{2}$
7	1230.5943	124 $4\frac{1}{4}$	9	1435.3675	134 $3\frac{5}{8}$
8	1235.7822	124 $7\frac{3}{8}$	10	1440.9668	134 $6\frac{3}{4}$
9	1240.9810	124 $10\frac{1}{2}$	11	1446.5802	134 $9\frac{7}{8}$
10	1246.1878	125 $1\frac{5}{8}$	43 ft.	1452.2046	135 1
11	1251.4084	125 $4\frac{3}{4}$	1	1457.8365	135 $4\frac{1}{8}$
40 ft.	1256.6400	125 $7\frac{7}{8}$	2	1463.4827	135 $7\frac{1}{4}$
1	1261.8794	125 11	3	1469.1397	135 $10\frac{1}{2}$
2	1267.1327	126 $2\frac{1}{4}$	4	1474.8044	136 $1\frac{5}{8}$
3	1272.3970	126 $5\frac{3}{8}$	5	1480.4833	136 $4\frac{3}{4}$
4	1277.6692	126 $8\frac{1}{2}$	6	1486.1731	136 $7\frac{7}{8}$
5	1282.9553	126 $11\frac{5}{8}$	7	1491.8705	136 11
6	1288.2523	127 $2\frac{3}{4}$	8	1497.5821	137 $2\frac{1}{8}$
7	1293.5572	127 $5\frac{7}{8}$	9	1503.3046	137 $5\frac{1}{4}$
8	1298.8760	127 9	10	1509.0348	137 $8\frac{3}{8}$
9	1304.2057	128 $0\frac{1}{4}$	11	1514.7791	137 $11\frac{5}{8}$
10	1309.5433	128 $3\frac{3}{8}$	44 ft.	1520.5344	138 $2\frac{3}{4}$
11	1314.8949	128 $6\frac{1}{2}$	1	1526.2971	138 $5\frac{7}{8}$
41 ft.	1320.2574	128 $9\frac{5}{8}$	2	1532.0742	138 9
1	1325.6276	129 $0\frac{3}{4}$	3	1537.8622	139 $0\frac{1}{8}$
2	1331.0119	129 $3\frac{7}{8}$	4	1543.6578	139 $3\frac{1}{4}$
3	1336.4071	129 7	5	1549.4676	139 $6\frac{3}{8}$
4	1341.8101	129 $10\frac{1}{8}$	6	1555.2883	139 $9\frac{5}{8}$
5	1347.2271	130 $1\frac{3}{8}$	7	1561.1165	140 $0\frac{3}{4}$
6	1352.6551	130 $4\frac{1}{2}$	8	1566.9591	140 $3\frac{7}{8}$
7	1358.0908	130 $7\frac{5}{8}$	9	1572.8125	140 $7\frac{1}{2}$
8	1363.5406	130 $10\frac{3}{4}$	10	1578.6735	140 $10\frac{1}{8}$
9	1369.0012	131 $1\frac{7}{8}$	11	1584.5488	141 $1\frac{1}{4}$
10	1374.4697	131 5	45 ft.	1590.4350	141 $4\frac{3}{8}$
11	1379.9521	131 $8\frac{1}{8}$	1	1596.3286	141 $7\frac{1}{2}$
42 ft.	1385.4456	131 $11\frac{3}{8}$	2	1602.2366	141 $10\frac{3}{4}$
1	1390.2467	132 $2\frac{1}{2}$	3	1608.1555	142 $1\frac{7}{8}$

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
4	1614.0819	142 5	9	1790.7610	150 0⅛
5	1620.0226	142 8⅜	10	1797.0145	150 3¼
6	1625.9743	142 11¼	11	1803.2826	150 6⅜
7	1631.9334	143 2⅜	48 ft.	1809.5616	150 9½
8	1637.9068	143 5½	1	1815.8477	151 0⅝
9	1643.8912	143 8¾	2	1822.1485	151 3¾
10	1649.8831	143 11⅞	3	1828.4602	151 6⅞
11	1655.8892	144 3	4	1834.7791	151 10⅛
46 ft.	1661.9064	144 6⅛	5	1841.1127	152 1¼
1	1667.9308	144 9¼	6	1847.4571	152 4⅜
2	1673.9698	145 0⅜	7	1853.8087	152 7½
3	1680.0196	145 3½	8	1860.1750	152 10⅝
4	1686.0769	145 6⅝	9	1866.5521	153 1¾
5	1692.1485	145 9⅞	10	1872.9365	153 4⅞
6	1698.2311	146 1⅛	11	1879.3355	153 8⅛
7	1704.3210	146 4⅜	49 ft.	1885.7454	153 11¼
8	1710.4254	146 7¼	1	1892.1724	154 2⅜
9	1716.5407	146 10⅜	2	1898.5041	154 5½
10	1722.6634	147 1½	3	1905.0367	154 8⅝
11	1728.8005	147 4⅝	4	1911.4965	154 11⅞
47 ft.	1734.9486	147 7¾	5	1917.9609	155 2⅞
1	1741.1039	147 11	6	1924.4263	155 6
2	1747.2738	148 2⅛	7	1930.9188	155 9¼
3	1753.4545	148 5¼	8	1937.3159	156 0⅛
4	1759.6426	148 8⅜	9	1943.9140	156 3½
5	1765.8452	148 11½	10	1950.4392	156 6⅝
6	1772.0587	149 2⅝	11	1956.9691	156 9¾
7	1778.2795	149 5⅞	50 ft.	1963.5000	157 0⅞
8	1784.5148	149 8⅞			

Table exhibiting the Temperatures and Volumes of Steam generated under different pressures.

Pressure in lbs. per square inch, atmospheric pressure included.	Temperature in degrees of Fahrenheit.	Volumes of steam compared with the volume of water.	Cubic inches of water in a cubic foot of steam.	Pressure in lbs. per square inch, atmospheric pressure included.	Temperature in degrees of Fahrenheit.	Volumes of steam compared with the volume of water.	Cubic inches of water in a cubic foot of steam.
15	213·0	1669	1·035	48	279.7	573	3·015
16	216·4	1572	1·099	49	281·0	562	3·074
17	219·6	1487	1·162	50	282·3	552	3·130
18	222·6	1410	1·226	51	283·6	542	3·188
19	225·6	1342	1·287	52	284·8	532	3·248
20	228·3	1280	1·350	53	286·0	523	3·304
21	231·0	1224	1·411	54	287·2	514	3·361
22	233·6	1172	1·474	55	288·4	506	3·415
23	236·1	1125	1·536	56	289·6	498	3·469
24	238·4	1082	1·597	57	290·7	490	3·526
25	240·7	1042	1·658	58	291·9	482	3·585
26	243·0	1005	1·719	59	293·0	474	3·645
27	245·1	971	1·779	60	294·1	467	3·700
28	247·2	939	1·840	61	294·9	460	3·756
29	249·2	909	1·910	62	295·9	453	3·814
30	251·2	882	1·959	63	297·0	447	3·865
31	253·1	855	2·021	64	298·1	440	3·927
32	255·0	831	2·079	65	299·1	434	3·981
33	256·8	808	2·138	66	300·1	428	4·037
34	258·6	786	2·198	67	301·2	422	4·094
35	260·3	765	2·258	68	302·2	417	4·143
36	262·0	746	2·316	69	303·2	411	4·204
37	263·7	727	2·376	70	304·2	406	4·256
38	265·3	710	2·433	71	305·1	401	4·309
39	266·9	693	2·493	72	306·1	396	4·363
40	268·4	677	2·552	73	307·1	391	4·419
41	269·9	662	2·610	74	308·0	386	4·476
42	271·4	647	2·670	75	308·9	381	4·535
43	272·9	634	2·725	76	309·9	377	4·583
44	274·3	620	2·787	77	310·8	372	4·645
45	275·7	608	2·842	78	311·7	368	4·695
46	277·1	596	2·899	79	312·6	364	4·747
47	278·4	584	2·958	80	313·5	359	4 812

Table by which to ascertain the amount of lap necessary on the steam side of a slide-valve to cut the steam off at various fractional parts of the stroke

To cut the steam off, after the piston has passed through						
$\frac{1}{2}$	$\frac{7}{12}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{5}{6}$	$\frac{7}{8}$	$\frac{11}{12}$
of its stroke. Multiply the given stroke of the valve by						
·354	·323	·289	·250	·204	·177	144
and the product is the lap of the valve in terms of the stroke.						

Example.—Required the lap necessary to cut the steam off at the end of five-sixths of the stroke, the stroke of the valve being twelve inches, and without lead. $204 \times 12 = 2{\cdot}448$ inches.

As lead is not taken into account because of different quantities being required to different applications of the steam-engine, subtract from the lap half the lead; the remainder is the lap required. Thus, suppose the lead equal $\cdot 25 \div 2 = \cdot 125$ and $2{\cdot}448 - \cdot 125 = 2{\cdot}323$ inches, the lap with one-fourth inch of lead as given.

Table of the Mean Elastic Force of Steam in pounds per square inch, at various grades of Expansion.

Initial density of the steam in lbs. per square inch.	Dense steam cut off after the piston has passed through the following fractional parts of the stroke:						
	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{2}{5}$	$\frac{1}{2}$	$\frac{3}{5}$	$\frac{3}{4}$	$\frac{4}{5}$
9	4·69	5·37	6·89	7·62	8·13	8·67	8·80
10	5·22	5·97	7·67	8·46	9·03	9·64	9·78
11	5·74	6·56	8·43	9·31	9·94	10·60	10·76
12	6·26	7·16	9·19	10·16	10·84	11·57	11·74
13	6·78	7·75	9·96	11·01	11·75	12·53	12·72
14	7·31	8·53	10·73	11·85	12·65	13·49	13·97
15	7·83	8·95	11·49	12·69	13·55	14·46	14·68
16	8·35	9·54	12·26	13·54	14·46	15·42	15·66
17	8·87	10·14	13·03	14·39	15·36	16·38	16·63
18	9·39	10·74	13·79	15·24	16·27	17·35	17·61
19	9·92	11·33	14.56	16·81	17·17	18·31	18·59
20	10·44	11·93	15·33	16·93	18·07	19·28	19·57
25	13·04	14·91	19·16	21·16	22·59	24·09	24·46
30	15·65	17·89	22·99	25·39	27·11	28·91	29·35
35	18·26	20·88	26·83	29·63	31·63	33·73	34·24
40	20·87	23·86	30·66	33·86	36·15	38·55	39·14
45	23·48	26·84	34·88	38·09	40·66	43·37	44·03
50	26·09	29·82	38·32	42·33	45·18	48·19	48·92

Atmospheric pressure not included.

Example.—If dense steam be admitted to the cylinder of an engine at a pressure of 17 pounds per square inch, and cut off when the piston has moved through two-fifths of the stroke, the mean elastic pressure during the whole stroke will be 13·03 pounds per square inch, as obtained by initial density and expansive force.

Table by which to find the relative state of Piston and Exhaust after Expansion.

Cover on the exhausting side of the valve in parts of the length of its stroke.	Steam cut off at 1-3d from the end of the stroke.		Steam cut off at 1-4th from the end of the stroke.		Steam cut off at 1-6th from the end of the stroke		Steam cut off at 1-8th from the end of the stroke.	
	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)
1-8th	·178	·033	·143	·019	·109	·008	·093	·004
1-16th	·130	·060	·100	·040	·171	·022	·058	·015
1-32d	·113	·073	·085	·051	·058	·033	·043	·023
0	·029	·092	·067	·067	·043	·043	·038	·033

Example from the Table.—Suppose an engine with a stroke of six feet, or 72 inches, and the steam cut off when the piston is one-third from the end of its stroke, the cover on the exhaust side of the valve being 1-32d of its stroke, the relative positions will be the following:—

In a line with 1-32d and under 1-3d is ·113 and ·073; therefore $·113 \times 72 = 8·136$ inches the piston is from the end of the stroke, when the exhausting-port before the piston is shut, and $·073 \times 72 = 5·256$ inches the piston is from the end of the stroke, when the exhausting-port behind it is open

Table of Cylinders, with proportionate strokes for Steam-engines of nominal horse-power; the dense steam for Condensing Engines being seven pounds per square inch.

Stationary Condensing Engines.			Marine Condensing Engines.			High-pressure, or Non-condensing Engines.				
Horse-power.	Diameter of cylinders in inches.	Proportionate strokes in feet.	Horse-power.	Diameter of cylinders in inches.	Proportionate strokes in feet.	Horse-power.	Diameter of cylinders in inches, the force of the dense steam per square inch being 25 lbs.	30 lbs.	40 lbs.	50 lbs.
2	9	1¾	10	20	2	1	3¾	3½	3	2¾
3	11	2	12	21½	2	1½	4½	4¼	3⅝	3¼
4	12	2¼	15	23½	2¼	2	5¼	4⅝	4¼	3¾
5	13½	2½	16	24½	2½	2½	5¾	5⅛	4⅝	4¼
6	14½	2¾	18	25¼	2½	3	6½	6	5	4½
8	16½	3	20	26½	2½	3½	6¾	6¼	5½	4⅞
10	18	3¼	25	28½	3	4	7½	6¾	6	5¼
12	19½	3½	30	31½	3	4½	7¾	7⅛	6¼	5⅝
14	21	3½	35	33½	3¼	5	8¼	7½	6½	5⅞
15	21½	3¾	40	36½	3¼	5½	8½	7⅞	6⅞	6⅛
16	22	4	45	37½	3½	6	9	8¼	7	6½
18	23	4¼	50	39½	3½	6½	9¼	8⅝	7½	6⅝
20	24½	4½	55	40½	4	7	9¾	9	7¾	6⅞
22	25¼	4½	60	43	4	7½	10	9¼	8	7¼
24	26½	4¾	65	44	4	8	10½	9¾	8¼	7¼
25	26¾	5	70	46	4¼	8½	10¾	9⅞	8½	7⅝
26	27	5	75	46¾	4½	9	11⅛	10¼	8¾	7⅞
28	27½	5½	80	48	4½	10	11¾	11	9½	8½
30	28½	5½	85	49	4¾	11	12½	11⅜	9¾	8¾
35	30½	5¾	90	50	4¾	12	13	12	10⅛	9¼
40	32½	6	95	52	4¾	13	13¼	12¼	10⅞	9⅜
45	34¼	6	100	52½	5	14	14	12¾	11⅛	10
50	36	6¼	110	55	5	15	14⅝	13⅛	11⅜	10¼
55	37½	6¼	115	56¼	5	16	15	13¾	12	10½
60	39	6½	120	57	5½	17	15¼	14	12½	10¾
65	40½	6½	125	58	5½	18	15¾	14½	12¾	11¼
70	41½	7	130	59	5½	19	16¼	14¾	13¼	11½
75	43	7	135	60	5¾	20	16¾	15¼	13½	11¾
80	44	7½	140	61	5¾	25	18½	17¼	15	13¼
85	45¼	7½	145	62	5¾	30	20¼	19¾	16½	14½
90	46	8	150	62½	6	35	21½	20¼	17¼	15½
95	47¼	8	175	67½	6	40	23	21⅜	18½	16¾
100	48½	8	200	71½	6½	Quantity of water for feed in gallons per minute to each horse-power,				
110	51	8	250	79½	6½					
120	52½	8½	260	81	6½					
130	54¼	9	270	81¾	7					
140	56	9	280	83	7	equal	·45	·5	·61	·72

Table of Nominal Velocities for the Pistons of Steam-engines, with given length of strokes

Stationary Condensing Engines.			Marine Engines.			High-pressure, or Non-condensing Engines.		
Length in feet and in.	Num. per min.	Velocity in feet per min.	Length in feet and in.	Num. per min.	Velocity in feet per min.	Length in feet and in.	Number per minute.	Velocity in feet per min.
1 9	46	161	2 0	42	168	1 0	80	160
2 0	42	168	2 3	39½	177¾	1 3	70	175
2 3	38	171	2 6	38	190	1 6	62	186
2 6	35	175	3 0	32	192	1 9	55	192½
2 9	32	176	3 3	29¾	193⅜	2 0	50	200
3 0	30	180	3 6	27¾	194¼	2 3	46	207
3 3	28½	185¼	4 0	24½	196	2 6	42½	212½
3 6	27	189	4 3	23½	199¾	2 9	39½	217¼
3 9	26	195	4 6	22½	202½	3 0	37	222
4 0	25	200	4 9	21½	204¼	3 3	35	228½
4 3	24	204	5 0	21	210	3 6	33	231
4 6	23	207	5 6	19½	214½	3 9	31	232½
5 0	21½	215	5 9	19	218½	4 0	29½	236
5 6	20	220	6 0	18½	222	4 6	27	243
6 0	19	228	6 6	17¼	224¼	5 0	24¾	247½
7 0	17½	245	7 0	16½	231	5 6	23	253
8 0	16	256	7 6	15½	232½	6 0	22	254

Table of Decimal Equivalents to Fractional Parts of Lineal Measures.

One inch, the integer or whole number.

·9375 = 7/8 and 1/16	·5625 = 1/2 and 1/16	·25 = 1/4
·875 = 7/8	·5 = 1/2	·1875 = 1/8 and 1/16
·8125 = 3/4 and 1/16	·4375 = 3/8 and 1/16	·125 = 1/8
·75 = 3/4	·375 = 3/8	·0625 = 1/16
·6875 = 5/8 and 1/16	·3152 = 1/4 and 1/16	·03125 = 1/32
·625 = 5/8		

One foot, or 12 inches the integer.

·9166 = 11 inches.	·4166 = 5 inches.	·0625 = 3/4 of inch.
·6338 = 10 "	·3333 = 4 "	·05208 = 5/8 "
·75 = 9 "	·25 = 3 "	·04166 = 1/2 "
·6666 = 8 "	·1666 = 2 "	·03125 = 3/8 "
·5833 = 7 "	·0833 = 1 "	·02083 = 1/4 "
·5 = 6 "	·07291 = 7/8 "	·1041 = 1/8 "

Table of Approximate Numbers, for various purposes.

Diameter of a circle	×	3·1416	= the circumference.
Circumference "	×	·31831	= the diameter.
Diameter "	×	·8862	= the side of an equal square.
Side of a square.....	×	1·128	= the diameter of an equal circle.
Square of diameter	×	·7854	= the area of a circle.
Square root of area	×	1·12837	= the diameter of equal circle.
Square of the diameter of a sphere	×	3·1416	= convex surface.
Cube of ditto.....	×	·5236	= solidity.
Diameter of a sphere	×	·806	= dimensions of equal cube.
Diameter of a sphere	×	·6667	= length of equal cylinder.
Square inches.....	×	·00695	= square feet.
Cubic inches.....	×	·00058	= cubic feet.
Cubic feet.....	×	·03704	= cubic yards
Cylindrical inches...	×	·0004546	= cubic feet.
Cylindrical feet	×	·02909	= cubic yards.
Cubic inches.....	×	·003607	= imperial gallons.
Cubic feet.....	×	·6232	= "
Cylindrical inches...	×	·002832	= "
Cylindrical feet	×	4·895	= "
183·346 circular inches.....			= 1 square foot.
2200 cylindrical inches.....			= 1 cubic foot.
Avoirdupois pounds	×	·009	= cwts.
Avoirdupois pounds	×	·00045	= tons.
Lineal feet.....	×	·00019	= English statute miles.
Lineal yards.....	×	·000568	= "

Table of Squares, Cubes, Square and Cube Roots of Numbers.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
1	1	1	1·0000000	1·0000000
8	4	2	1·4142136	1·2599210
27	9	3	1·7320508	1·4422496
64	16	4	2·0000000	1·5874011
125	25	5	2·2360680	1·7099759
216	36	6	2·4494897	1·8171216
343	49	7	2·6457513	1·9129312
512	64	8	2·8284271	2·0000000
729	81	9	3·0000000	2·0800837
1000	100	10	3·1622777	2·1544347
1331	121	11	3·3166248	2·2239801
1728	144	12	3·4641016	2·2894286
2197	169	13	3·6055513	2·3513347
2744	196	14	3·7416574	2·4101422
3375	225	15	3·8729833	2·4262121
4096	256	16	4·0000000	2·5198421
4913	289	17	4·1231056	2·6712816
5832	324	18	4·2426407	2·6207417
6859	361	19	4·3588989	2·6684016
8000	400	20	4·4721360	2·7144177
9261	441	21	4·5825757	2·7589243
10648	484	22	4·6904158	2·8020393
12167	529	23	4·7958315	2·8438670
13824	576	24	4·8989795	2·8844991
15625	625	25	5·0000000	2·9240177
17576	676	26	5·0990195	2·9624960
19683	729	27	5·1961524	3·0000000
21952	784	28	5·2915026	3·0365889
24389	841	29	5·3851648	3·0723168
27011	900	30	5·4772256	3·1072325
29791	961	31	5·5677644	3·1413806
32768	1024	32	5·6568542	3·1748021
35937	1089	33	5·7445626	3·2075343
39304	1156	34	5·8309519	3·2396118

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
42875	1225	35	5·9164798	3·2710663
46656	1296	36	6·0000000	3·3019272
50653	1369	37	6·0827625	3·3322218
54872	1444	38	6·1644140	3·3619754
59319	1521	39	6·2449980	3·3912114
64000	1600	40	6·3245553	3·4199519
68921	1681	41	6·4031242	3·4482172
74088	1764	42	6·4807407	3·4760266
79507	1849	43	6·5574385	3·5033981
85184	1936	44	6·6332496	3·5303483
91125	2025	45	6·7082039	3·5568933
97336	2116	46	6·7823300	3·5830479
103823	2209	47	6·8556546	3·6088261
110592	2304	48	6·9282032	3·6342411
117649	2401	49	7·0000000	3·6593057
125000	2500	50	7·0710678	3·6840314
132651	2601	51	7·1414284	3·7084298
140608	2704	52	7·2111026	3·7325111
148877	2809	53	7·2801099	3·7562850
157464	2916	54	7·3484692	3·7797631
166375	3025	55	7·4161985	3·8029525
175616	3136	56	7·4833148	3·8258624
185193	3249	57	7·5498344	3·8485011
195012	3364	58	7·6157731	3·8708766
205379	3481	59	7·6811457	3·8929965
216000	3600	60	7·7459667	3·9147632
226981	3721	61	7·8102497	3·9304972
238328	3844	62	7·8740079	3·9578915
250047	3969	63	7·9372539	3·9790571
262144	4096	64	8·0000000	4·0000000
274625	4225	65	8·0622577	4·0207256
287496	4356	66	8·1240384	4·0412401
300763	4489	67	8·1853528	4·0615480
314432	4624	68	8·2462113	4·0816551

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
328509	4761	69	8·3066239	4·1015661
343000	4900	70	8·3666003	4·1212853
357911	5041	71	8·4261498	4·1408178
373248	5184	72	8·4852814	4·1601676
389017	5329	73	8·5440037	4·1793390
405224	5476	74	8·6023253	4·1983364
421875	5625	75	8·6602540	4·2171633
438976	5776	76	8·7177979	4·2358286
456533	5929	77	8·7749644	4·2543210
474552	6084	78	8·8317609	4·2726586
493039	6241	79	8·8881944	4·2908404
512000	6400	80	8·9442799	4·3088695
531441	6561	81	9·0000000	4·3267487
551368	6724	82	9·0553851	4·3444815
571787	6889	83	9·1104336	4·3620707
592704	7056	84	9·1631514	4·3795191
614125	7225	85	9·2195445	4·3968296
636056	7396	86	9·2736185	4·4140049
658503	7569	87	9·3273791	4·4310476
681472	7744	88	9·3808315	4·4470692
704969	7921	89	9·4339811	4·4647451
729000	8100	90	9·4868330	4·4814047
753571	8281	91	9·5393920	4·4979414
778688	8464	92	9·5916630	4·5143574
804357	8649	93	9·6436508	4·5306549
830584	8836	94	9·6953597	4·5468359
857374	9025	95	9·7467943	4·5629026
884736	9216	96	9·7979590	4·5788570
912073	9409	97	9·8488578	4·5943009
949912	9604	98	9·8994949	4·6104363
970299	9801	99	9·9498744	4·6260650
1000000	10000	100	10·0000000	4·6415888
1030301	10201	101	10·0498756	4·6570095
1061228	10404	102	10·0995049	4·6723287

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
1092727	10609	103	10·1488916	4·6875482
1124864	10816	104	10·1980390	4·7026694
1157625	11025	105	10·2469508	4·7176940
1191016	11236	106	10·2956301	4·7326235
1225043	11449	107	10·3440804	4·7474594
1259712	11664	108	10·3923048	4·7622032
1295029	11881	109	10·4403065	4·7768562
1331000	12100	110	10·4880885	4·7914199
1367631	12321	111	10·5356538	4·8058995
1404928	12524	112	10·5830052	4·8202845
1442897	12769	113	10·6301458	4·8343881
1481344	12996	114	10·6770783	4·8488076
1520875	13225	115	10·7238053	4·8629442
1560896	13456	116	10·7703296	4·8769900
1601613	13689	117	10·8166538	4·8909732
1643032	13924	118	10·8627805	4·9048681
1685159	14161	119	10·9087121	4·9186847
1728000	14400	120	10·9544512	4·9324242
1771561	14641	121	11·0000000	4·9460874
1815848	14834	122	11·0453610	4·9596757
1860867	15129	123	11·0905365	4·9731898
1906624	15376	124	11·1355287	4·9866310
1953125	15625	125	11·1803399	5·0000000
2000376	15876	126	11·2249722	5·0132979
2048383	16129	127	11·2694277	5·0265257
2097152	16384	128	11·3137085	5·0396842
2146689	16641	129	11·3578167	5·0527743
2197000	16900	130	11·4017543	5·0657970
2248091	17161	131	11·4455231	5·0787531
2299968	17424	132	11·4891253	5·0916434
2352637	17689	133	11·5325626	5·1044687
2408104	17956	134	11·5758369	5·1172259
2460375	18225	135	11·6189500	5·1299278
2515456	18496	136	11·6619038	5·1425632

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
2571353	18769	137	11·7046999	5·1550367
2628072	19044	138	11·7473444	5·1676493
2685619	19321	139	11·7898261	5·1801015
2744000	19600	140	11·8321596	5·1924941
2803221	19881	141	11·8743421	5·2048279
2863288	20164	142	11·9163753	5·2171034
2924207	20449	143	11·9582607	5·2293315
2985984	20736	144	12·0000000	5·2414828
3048625	21025	145	12·0415946	5·2535879
3112136	21316	146	12·0830460	5·2656374
3176523	21609	147	12·1243557	5·2776321
3241792	21904	148	12·1655251	5·2895725
3307949	22211	149	12·2065556	5·3014592
3375000	22500	150	12·2474487	5·3132928
3442951	22801	151	12·2882057	5·3250740
3511008	23104	152	12·3288280	5·3368033
3581577	23409	153	12·3693169	5·3484812
3652264	23716	154	12·4096736	5·3601084
3723875	24025	155	12·4498996	5·3716854
3796416	24336	156	12·4899960	5·3832126
3869893	24649	157	12·5299641	5·3946907
3944312	24964	158	12·5698051	5·4061202
4019679	25281	159	12·6095202	5·4178015
4096000	25600	160	12·6491106	5·4258352
4173281	25921	161	12·6885775	5·4401218
4251528	26244	162	12·7279221	5·4513618
4330747	26569	163	12·7671453	5·4625556
4410944	26896	164	12·8062485	5·4737037
4492125	27225	165	12·8432326	5·4848066
4574296	27556	166	12·8840987	5·4958647
4657463	27889	167	12·9228480	5·5068784
4741632	28224	168	12·9614814	5·5178484
4826809	28561	169	13·0000000	5·5287748
4913000	28900	170	13·0384048	5·5396583

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
5000211	29241	171	13·0766968	5·5504990
5088448	29584	172	13·1148770	5·5612578
5177717	29929	173	13·1529464	5·5720546
5268024	30276	174	13·1909060	5·5827702
5359375	30625	175	13·2287566	5·5934447
5451776	30976	176	13·2664992	5·6040787
5545233	31329	177	13·3041347	5·6146724
5639752	31684	178	13·3416641	5·6252263
5735339	32041	179	13·3790882	5·6357408
5832000	32400	180	13·4164079	5·6462162
5929741	32761	181	13·4536240	5·6566528
6028568	33124	182	13·4907376	5·6670511
6128487	33489	183	13·5277493	5·6774114
6229504	33856	184	13·5646600	5·6877340
6331625	34225	185	13·6014705	5·6980192
6434856	34596	186	13·6381817	5·7082675
6539203	34969	187	13·6747943	5·7184791
6644672	35344	188	13·7113092	5·7286543
6751260	35721	189	13·7477271	5·7387936
6859000	36100	190	13·7840488	5·7488971
6967871	36481	191	13·8202750	5·7589652
7077888	36864	192	13·8564065	5·7689982
7189517	37249	193	13·8924400	5·7789966
7301384	37636	194	13·9283883	5·7889604
7414875	38025	195	13·9642400	5·7988900
7529536	38416	196	14·0000000	5·8087857
7645373	38809	197	14·0356688	5·8186479
7762392	39204	198	14·0712473	5·8284867
7880599	39601	199	14·1067360	5·8382725
8000000	40000	200	14·1421356	5·8480355

Table of Hyperbolic Logarithms.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
1·01	·0099503	1·40	·3364722	1·79	·5822156
1·02	·0198026	1·41	·3435897	1·80	·5877866
1·03	·0295588	1·42	·3506568	1·81	·5933268
1·04	·0392207	1·43	·3576744	1·82	·5988365
1·05	·0487902	1·44	·3646431	1·83	·6043159
1·06	·0582689	1·45	·3715635	1·84	·6097655
1·07	·0676586	1·46	·3784364	1·85	·6151856
1·08	·0769610	1·47	·3852624	1·86	·6205764
1·09	·0861777	1·48	·3920420	1·87	·6259384
1·10	·0953102	1·49	·3987761	1·88	·6312717
1·11	·1043600	1·50	·4054651	1·89	·6365768
1·12	·1133287	1·51	·4121096	1·90	·6418538
1·13	·1222176	1·52	·4187103	1·91	·6471032
1·14	·1310283	1·53	·4252677	1·92	·6523251
1·15	·1397619	1·54	·4317824	1·93	·6575200
1·16	·1484200	1·55	·4382549	1·94	·6626879
1·17	·1570037	1·56	·4446858	1·95	·6678293
1·18	·1655144	1·57	·4510756	1·96	·6729444
1·19	·1739533	1·58	·4574248	1·97	·6780335
1·20	·1823215	1·59	·4637340	1·98	·6830968
1·21	·1962030	1·60	·4700036	1·99	·6881346
1·22	·1988508	1·61	·4762341	2·00	·6931472
1·23	·2070141	1·62	·4824261	2·01	·6981347
1·24	·2151113	1·63	·4885800	2·02	·7030974
1·25	·2231435	1·64	·4946962	2·03	·7080357
1·26	·2341117	1·65	·5007752	2·04	·7129497
1·27	·2390169	1·66	·5068175	2·05	·7178397
1·28	·2468600	1·67	·5128236	2·06	·7227059
1·29	·2546422	1·68	·5187937	2·07	·7275485
1·30	·2623642	1·69	·5247285	2·08	·7323678
1·31	·2700271	1·70	·5306282	2·09	·7316470
1·32	·2776317	1·71	·5364933	2·10	·7419373
1·33	·2851789	1·72	·5423242	2·11	·7466879
1·34	·2926696	1·73	·5481214	2·12	·7514160
1·35	·3001045	1.74	·5538851	2·13	·7561219
1·36	·3074846	1·75	·5596157	2·14	·7608058
1·37	·3148107	1·76	·5653138	2·15	·7654678
1·38	·3220834	1·77	·5709795	2·16	·7701082
1·39	·3293037	1·78	·5766133	2·17	·7747271

Table of Hyperbolic Logarithms—Continued.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
2·18	·7793248	2·57	·9439058	2·96	1·0851892
2·19	·7839015	2·58	·9477893	2·97	1·0885619
2·20	·7884573	2·59	·9516578	2·98	1·0919233
2·21	·7929025	2·60	·9555114	2·99	1·0952733
2·22	·7975071	2·61	·9593602	3·00	1·0986123
2·23	·8021015	2·62	·9631743	3·01	1·1019400
2·24	·8064758	2·63	·9669838	3·02	1·1052568
2·25	·8109302	2·64	·9707789	3·03	1·1085626
2·26	·8153648	2·65	·9745596	3·04	1·1118575
2·27	·8197798	2·66	·9783261	3·05	1·1511415
2·28	·8241754	2·67	·9820784	3·06	1·1184149
2·29	·8285518	2·68	·9858167	3·07	1·1216775
2·30	·8329091	2·69	·9895411	3·08	1·1249295
2·31	·8372475	2·70	·9932517	3·09	1·1281710
2·32	·8415671	2·71	·9969486	3·10	1·1314021
2·33	·8458682	2·72	1·0006318	3·11	1·1346227
2·34	·8501509	2·73	1·0043015	3·12	1·1378330
2·35	·8544153	2·74	1·0079579	3·13	1·1410330
2·36	·8586616	2·75	1·0116008	3·14	1·1442227
2·37	·8628899	2·76	1·0152306	3·15	1·1474024
2·38	·8671004	2·77	1·0188473	3·16	1·1505720
2·39	·8712933	2·78	1·0224509	3·17	1·1537315
2·40	·8754687	2·79	1·0260415	3·18	1·1568811
2·41	·8796267	2·80	1·0296194	3·19	1·1600209
2·42	·8837675	2·81	1·0331844	3·20	1·1631508
2·43	·8878912	2·82	1·0367368	3·21	1·1662709
2·44	·3919980	2·83	1·0402766	3·22	1·1693813
2·45	·8960880	2·84	1·0438040	3·23	1·1724821
2·46	·9001613	2·85	1·0473189	3·24	1·1755733
2·47	·9042181	2·86	1·0508216	3·25	1·1786549
2·48	·9082585	2·87	1·0543120	3·26	1·1817271
2·49	·9122826	2·88	1·0577902	3·27	1·1847899
2·50	·9162907	2·89	1·0612564	3·28	1·1878434
2·51	·9202827	2·90	1·0647107	3·29	1·1908875
2·52	·9242589	2·91	1·0681530	3·30	1·1939224
2·53	·9282193	2·92	1·0715836	3·31	1·1969481
2·54	·9321640	2·93	1·0750024	3·32	1·1999647
2·55	·9360933	2·94	1·0784095	3·33	1·2029722
2·56	·9400072	2·95	·0818051	3·34	1·2059707

Table of Hyperbolic Logarithms—Continued.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
3·35	1·2089603	3·74	1·3190856	4·13	1·4182774
3·36	1·2119409	3·75	1·3217558	4·14	1·4206957
3·37	1·2149127	3·76	1·3244189	4·15	1·4231083
3·38	1·2178757	3·77	1·3271749	4·16	1·4255150
3·39	1·2208299	3·78	1·3297240	4·17	1·4279160
3·40	1·2237754	3·79	1·3323660	4·18	1·4323112
3·41	1·2267122	3·80	1·3350010	4·19	1·4327007
3·42	1·2296405	3·81	1 3376291	4·20	1·4350845
3·43	1·2325605	3·82	1·3402504	4·21	1·4374626
3·44	1·2354714	3·83	1·3428648	4·22	1·4398351
3·45	1·2387420	3·84	1·3454723	4·23	1·4422020
3·46	1·2412685	3·85	1·3480731	4·24	1·4445632
3·47	1·2441545	3·86	1·3506671	4·25	1·4469189
3·48	1·2470322	3·87	1·3532544	4·26	1·4492691
3·49	1·2499017	3·88	1·3558351	4·27	1·4516138
3·50	1·2527629	3·89	1·3584091	4·28	1·4539530
3·51	1·2556160	3·90	1·3609765	4·29	1·4562867
3·52	1·2584609	3·91	1·3635373	4·30	1·4586149
3·53	1·2612978	3·92	1·3660916	4·31	1·4609379
3·54	1·2641266	3·93	1·3686394	4·32	1·4632553
3·55	1·2669475	3·94	1·3711807	4·33	1·4655635
3·56	1·2697605	3·95	1·3737156	4·34	1·4678743
3·57	1·2725655	3·96	1·3726440	4·35	1 4701758
3·58	1·2753627	3·97	1·3787661	4·36	1·4724720
3·59	1·2781521	3·98	1·3812818	4·37	1·4747630
3·60	1·2809338	3·99	1·3837912	4·38	1·4778487
3·61	1·2837077	4·00	1·3862943	4·39	1·4793292
3·62	1·2864740	4·01	1·3887912	4·40	1·4816045
3·63	1·2892326	4·02	1·3912818	4·41	1·4838746
3·64	1·2919836	4·03	1·3937663	4·42	1·4838746
3·65	1·2947271	4·04	1·3962446	4·43	1·4883995
3·66	1·2974631	4·05	1·3987168	4·44	1·4906543
3·67	1·3001916	4·06	1·4011829	4·45	1·4929040
3·68	1·3029127	4·07	1·4036429	4·46	1·4914870
3·69	1·3056264	4·08	1·4060969	4·47	1·4973883
3·70	1·3083328	4·09	1·4085449	4·48	1·4996230
3·71	1·3110318	4·10	1·4109869	4·49	1·5018527
3·72	1·3137236	4·11	1·4134230	4·50	1·5040774
3·73	1·3164082	4·12	1·4158531	4·51	1·5062971

Table of Hyperbolic Logarithms—Continued.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
4·52	1·5085119	4·91	1·5912739	5·30	1·6677068
4·53	1·5107219	4·92	1·5933085	5·31	1·6695918
4·54	1·5129269	4·93	1·5953389	5·32	1·6714733
4·55	1·5151272	4·94	1·5973653	5·33	1·6733512
4·56	1·5173226	4·95	1·5993875	5·34	1·6752256
4·57	1·5195132	4·96	1·6014057	5·35	1·6770965
4·58	1·5216990	4·97	1·6034198	5·36	1·6789639
4·59	1·5238800	4·98	1·6054298	5·37	1·6808278
4·60	1·5260563	4·99	1·6074358	5·38	1·6826882
4·61	1·5282278	5·00	1·6094379	5·39	1·6845453
4·62	1·5303947	5·01	1·6114359	5·40	1·6863989
4·63	1·5325568	5·02	1·6134300	5·41	1·6882491
4·64	1·5347143	5·03	1·6154200	5·42	1·6900958
4·65	1·5368672	5·04	1·6174060	5·43	1·6919391
4·66	1·5390154	5·05	1·6193882	5·44	1·6937790
4·67	1·5411590	5·06	1·6213664	5·45	1·6956155
4·68	1·5432981	5·07	1·6233408	5·46	1·6974487
4·69	1·5454325	5·08	1·6253112	5·47	1·6992786
4·70	1·5475625	5·09	1·6272778	5·48	1·7011051
4·71	1·5496879	5·10	1·6292405	5·49	1·7029282
4·72	1·5518087	5·11	1·6311994	5·50	1·7047481
4·73	1·5539252	5·12	1·6331544	5·51	1·7065646
4·74	1·5560371	5·13	1·6351056	5·52	1·7083778
4·75	1·5581446	5·14	1·6370530	5·53	1·7101878
4·76	1·5602476	5·15	1·6389967	5·54	1·7119944
4·77	1·5623462	5·16	1·6409365	5·55	1·7137979
4·78	1·5644405	5·17	1·6428726	5·56	1·7155981
4·79	1·5665304	5·18	1·6448050	5·57	1·7173950
4·80	1·5686159	5·19	1·6463336	5·58	1·7191887
4·81	1·5706971	5·20	1·6486586	5·59	1·7209792
4·82	1·5727739	5·21	1·6505798	5·60	1·7227666
4·83	1·5748464	5·22	1·6524974	5·61	1·7245507
4·84	1·5769147	5·23	1·6544112	5·62	1·7263316
4·85	1·5789787	5·24	1·6563214	5·63	1·7281004
4·86	1·5810384	5·25	1·6582280	5·64	1·7298840
4·87	1·5830939	5·26	1·6601310	5·65	1·7316555
4·88	1·5851452	5·27	1·6620303	5·66	1·7334238
4·89	1·5870923	5·28	1·6639260	5·67	1·7351891
4·90	1·5892352	5·29	1·6658182	5·68	1·7369512

Table of Hyperbolic Logarithms—Continued.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
5·69	1·7387102	5·93	1·7800242	6·17	1·8196988
5·70	1·7404661	5·94	1·7817091	6·18	1·8213182
5·71	1·7422189	5·95	1·7833112	6·19	1·8229351
5·72	1·7439687	5·96	1·7850704	6·20	1·8245103
5·73	1·7457155	5·97	1·7867469	6·21	1·8261608
5·74	1·7474591	5·98	1·7884205	6·22	1·8277639
5·75	1·7491998	5·99	1·7900914	6·23	1·8293763
5·76	1·7509374	6·00	1·7917594	6·24	1·8309801
5·77	1·7526720	6·01	1·7934247	6·25	1·8325814
5·78	1·7544036	6·02	1·7950872	6·26	1·8341801
5·79	1·7561323	6·03	1·7967470	6·27	1·8357763
5·80	1·7578579	6·04	1·7984040	6·28	1·8373699
5·81	1·7595805	6·05	1·8000582	6·29	1·8389610
5·82	1·7613002	6·06	1·8017098	6·30	1·8405496
5·83	1·7630170	6·07	1·8033586	6·31	1·8421356
5·84	1·7647380	6·08	1·8050047	6·32	1·8437191
5·85	1·7664416	6·09	1·8066481	6·33	1·8453002
5·86	1·7681496	6·10	1·8082887	6·34	1·8468787
5·87	1·7698546	6·11	1·8099267	6·35	1·8484547
5·88	1·7715567	6·12	1·8115621	6·36	1·8500283
5·89	1·7732559	6·13	1·8131947	6·37	1·8515994
5·90	1·7749523	6·14	1·8148247	6·38	1·8531680
5·91	1·7766458	6·15	1·8164520	6·39	1·8547342
5·92	1·7783364	6·16	1·8180767	6·40	1·8562979

Table of Natural Sines, Co-sines, Tangents, Co-tangents, Secants and Co-secants to every degree of the Quadrant.

Deg.	Sines.	Co-sines.	Tangents	Co-tangents.	Secants.	Co-secants	Deg.
0	·00000	1·00000	·00000	Infinite	1·00000	Infinite	90
1	·01745	·99985	·01746	57·2900	1·00015	57·2987	89
2	·03490	·99939	·03492	28·6363	1·00061	28·6537	88
3	·05234	·99863	·05241	19·0811	1·00137	19·1073	87
4	·06976	·99756	·06993	14·3007	1·00244	14·3356	86
5	·08716	·99619	·08749	11·4301	1·00382	11·4737	85
6	·10453	·99452	·10510	9·51236	1·00551	9·56677	84
7	·12187	·99255	·12278	8·14435	1·00751	8·20551	83
8	·13917	·99027	·14054	7·11537	1·00983	7·18530	82
9	·15643	·98769	·15836	6·31375	1·01246	6·39245	81
10	·17365	·98481	·17633	5·67128	1·01543	5·75877	80
11	·19081	·98163	·19438	5·14455	1·01872	5·24084	79
12	·20791	·97815	·21256	4·70463	1·02234	4·80973	78
13	·22495	·97437	·23087	4·33148	1·02630	4·44541	77
14	·24192	·97030	·24933	4·01078	1·03061	4·13356	76
15	·25882	·96593	·26795	3·73205	1·03588	3·86370	75
16	·27564	·96126	·28675	3·48741	1·04030	3·62796	74
17	·29237	·95630	·30573	3·27085	1·04569	3·42030	73
18	·30902	·95106	·32492	3·07768	1·05146	3·23607	72
19	·32557	·94552	·34433	2·90421	1·05762	3·07155	71
20	·34202	·93969	·36397	2·74748	1·06418	2·92380	70
21	·35837	·93358	·38386	2·60509	1·07114	2·79043	69
22	·37461	·92718	·40403	2·47509	1·07853	2·66947	68
23	·39073	·92060	·42447	2·35585	1·08636	2·55930	67
24	·40674	·91355	·44523	2·24004	1·09464	2·45859	66
25	·42262	·90631	·46631	2·14451	1·10338	2·36620	65
26	·43837	·89879	·48773	2·05030	1·11260	2·28117	64
27	·45399	·89101	·50952	1·96261	1·12233	2·20869	63
28	·46947	·88295	·53171	1·88073	1·13257	2·13005	62
29	·48481	·87462	·55431	1·80405	1·14335	2·06266	61
30	·50000	·86603	·57735	1·73205	1·15470	2·00000	60
31	·51504	·85717	·60086	1·66428	1·16663	1·94160	59
32	·52992	·84805	·62487	1·60033	1·17918	1·88708	58
33	·54464	·83867	·64941	1·53986	1·19236	1·83608	57
34	·55919	·82904	·67451	1·48256	1·20622	1·78829	56
35	·57358	·81915	·70021	1·42815	1·22077	1·74345	55
36	·58778	·80902	·72654	1·37638	1·23607	1·70130	54
37	·60181	·79863	·75355	1·32704	1·25214	1·66164	53
38	·61566	·78801	·78129	1·27994	1·26902	1·62427	52
39	·62932	·77715	·80978	1·23490	1·28676	1·58902	51
40	·64279	·76604	·83910	1·19175	1·30541	1·55572	50
41	·65606	·75471	·86929	1·15037	1·32611	1·52425	49
42	·66993	·74314	·90040	1·11061	1·34561	1·49448	48
43	·68200	·73135	·93251	1·07237	1·36706	1·46628	47
44	·69466	·71934	·96569	1·03553	1·39012	1·43956	46
45	·70711	·70711	1·00000	1·00000	1·41421	1·41421	45

Table of the Expansion of Air by Heat, that at 32° Fahrenheit being 1·000.

Fah.	Volume.	Fah.	Volume.	Fah.	Volume.
35° ...	1·007	85° ...	1·121	170° ...	1·295
40 ...	1·021	90 ...	1·132	180 ...	1·315
45 ...	1·032	95 ...	1·142	190 ...	1·334
50 ...	1·043	100 ...	1·152	200 ...	1·364
55 ...	1·055	110 ...	1·173	210 ...	1·372
60 ...	1·066	120 ...	1·194	212 ...	1·376
65 ...	1·077	130 ...	1·215	302 ...	1·558
70 ...	1·089	140 ...	1·235	392 ...	1·739
75 ...	1·099	150 ...	1·255	482 ...	1·919
80 ...	1·110	160 ...	1·275	572 ...	2·098

NOTE.—One hundred parts of pure air by weight contain 75 55 parts of nitrogen, 23·32 parts oxygen, and 1·3 carbonic acid, and watery vapour.

The weight or pressure of the atmosphere equal a column of water 34 feet in height, or a column of mercury 30 inches in height, or 14·7 pounds per square inch at a mean temperature.

The resistance of air increases as the square of the velocity, and the resistance per square foot as the velocity multiplied by ·002288.

Table of the Relative Indications of Barometer and Thermometer at the boiling points of Fresh Water.

When the Barometer indicates 30 inches, the boiling point is 212° Fah., and 0·589 of barometric pressure corresponds to a difference of 1° Fah.

Columns of Fresh Water in feet equal to columns of Mercury in inches.	Barometer, Height of Mercury in inches.	Thermometer, Degrees of Fahrenheit.
35·07	31	213·57
34·50	30·5	212·79
34·02	30	212·00
33·37	29·5	211·20
32·81	29	210·38
32·22	28·5	209·55
31·84	28	208·69
31·11	27·5	207·84
30·52	27	206·96
	In a vacuum, water boils at	98·00 to 100

To find the height of a mountain by the Barometer.

Rule 1.—Multiply the difference between 32° Fah. and the mean temperature of the air by ·21, and add the product to 87 if the mean temperature be above 32°, but subtract it if below.

Rule 2.—Multiply the sum or difference as found above by thirty times the difference between the barometric heights in tenths of inches, and divide the product by the mean of the barometric heights; the quotient is the approximated elevation.

Rule 3.—Multiply the difference between the mercurial temperatures by 2·833 feet, and add the product to the approximated elevation if that of the upper barometer be the greatest, otherwise subtract it; the result will be the corrected elevation in English feet.

Table of Specific Gravities.

Metals.	Weight, water being 1000.	Number of cubic inches in a pound.	Weight of a cubic inch in pounds.
Platina	19500	1·417	·7053
Pure gold	19258	1·435	·6965
Mercury	13560	2·04	·4902
Lead	11352	2·435	·4105
Pure silver	10474	2·638	·3788
Bismuth	9823	2·814	·3552
Copper	8788	3·146	·3178
Brass	7824	3·533	·3036
Iron, cast	7264	3·806	·263
Iron, bar	7700	3·592	·279
Steel	7833	3·530	·2833
Tin	7291	3·790	·2636
Zinc	7190	3·845	·26

Various Bodies.	Weight, water being 1000.	Weight of a cubic foot in pounds.	Number of cubic feet in a ton.
Marble, average	2720	170·0	13
Granite, do.	2651	165·6	13·5
Chalk, British	2781	173·8	12·75
Brick, red, common	2160	135·0	17·5
Brick, fire, Welsh	2408	150·5	14·5
Tallow, average	942	59·0	38·0
Ice, from fresh water	1001	53·0	35·5
Coal, Welsh	1526	95·3	24·7
Coal, Lancashire	1319	82·4	26·0
Coal, Scotch	1300	81·5	27·5
Coal, cannel	1272	79·5	28·0
Coal, Newcastle	1270	79·3	28·2
Coke, dry	755	47·0	47·6

Table of Specific Gravities—Continued.

Timber, Seasoned	Weight, water being 1000.	Weight of a cubic foot in pounds.	Number of cubic feet in a ton.
English oak	934	58	38·5
African oak	944	59	38·0
Riga oak	872	54	41·5
Beach oak	852	48	45·0
Ash oak	845	52	43·0
Mahogany, Spanish	800	50	45·0
Dantzic oak	756	47	48·0
Riga fir	753	47	48·0
Maple	752	47	47·5
Teak	750	46	48·5
Elm	673	42	53·0
American oak	672	42	53·0
Walnut	671	41·9	53·5
Pitch pine	660	41	54·5
Red pine	657	47	54·5
Poona	640	40	55·0
Mahogany, Honduras	637	40	55·0
Sycamore	604	38	59.0
Lime-tree	600	37	59·5
Cedar	561	35	64·0
Yellow pine	461	28	80·0
Cork	240	15	149·0
Pine, white	426	26	84·2

Table of Specific Gravities—Continued.

Liquids.	Weight, water being 1000.	Weight of an imp. gallon in pounds.
Water from the Dead Sea	1240	12·4
Water from the Mediterranean	1029	10·3
Water from the Irish Channel	1028	10·2
Water from the Baltic	1015	10·2
Vinegar	1010	10·1
Turpentine	991	9·8
Linseed oil	940	9·4
Whale oil	923	9·2
Proof spirit	922	9·2
Rape-seed oil	919	9·3
Olive oil	915	9·2
Alcohol, com.	837	8·3

Names of Gases, Atmospheric Air being 1000.	
Carbonic acid gas	1527
Oxygen	1111
Carburetted hydrogen	972
Nitrogen	969
Steam of water at 212°	623
Chlorine	470
Hydrogen	69

Table of the Weight of Bar Iron.

ROUND.					
Diameter in inches.	Length, one foot.		Diameter in inches.	Length, one foot.	
	Weight in pounds.	Weight in pounds.		Weight in pounds.	Weight in pounds.
¼	·164	·0137	3⅛	25·620	2·135
5/16	·256	·0233	3¼	27·709	2·309
⅜	·369	·0307	3⅜	29·881	2·490
7/16	·503	·0420	3½	32·170	2·681
½	·656	·0547	3⅝	34·472	2·873
9/16	·831	·0692	3¾	36·895	3·075
⅝	1·025	·0854	3⅞	39·390	3·283
11/16	1·241	·1034	4 in.	41·984	3·499
¾	1·476	·1230	4⅛	44·637	3·720
13/16	1·732	·1443	4¼	47·385	3·949
⅞	2·011	·1676	4⅜	53·132	4·428
15/16	2·306	·1921	4¾	59·187	4·932
1 in.	2·624	·2187	5 in.	65·585	5·465
1⅛	3·321	·2767	5¼	72·618	6·051
1¼	4·099	·3146	5½	79·370	6·614
1⅜	4·961	·4134	5¾	86·731	7·227
1½	5·913	·4927	6 in.	94·610	7·884
1⅝	6·928	·5773	6½	110·84	9·237
1¾	8·043	·6702	7 in.	128·68	10·723
1⅞	9·224	·7686	7½	147·58	12·298
2 in.	10·496	·8747	8 in.	167·94	13·995
2⅛	11·846	·9872	8½	189·54	15·795
2¼	13·283	1·107	9 in.	212·53	17·710
2⅜	14·797	1·233	9½	236·75	19·729
2½	16·396	1·366	10 in.	262·34	21·861
2⅝	18·146	1·512	10½	290·47	24·206
2¾	19·842	1·653	11 in.	317·48	26·457
2⅞	21·684	1·307	11½	346·93	28·911
3 in.	23·653	1·971	12 in.	378·44	31·537

Table of the Weight of Bar Iron—Continued.

SQUARE.					
Side of square in inches.	Length, one foot.		Side of square in inches.	Length, one foot.	
	Weight in pounds.	Weight in pounds.		Weight in pounds.	Weight in pounds.
¼	·209	·0174	2⅛	15·083	1·257
⅜	·470	·0391	2¼	16·909	1·409
½	·835	·0696	2⅜	18·840	1·570
⅝	1·305	·1087	2½	20·875	1·739
¾	1·879	·1565	2⅝	23·115	1·926
⅞	2·558	·2131	2¾	25·259	2·105
1 in.	3·340	·2783	2⅞	27·608	2·301
1⅛	4·228	·3523	3 in.	30·070	2·506
1¼	5·219	·4349	3¼	35·279	2·940
1⅜	6·315	·5262	3½	40·916	3·409
1½	7·516	·6263	3¾	46·969	3·914
1⅝	8·820	·7350	4 in.	53·440	4·455
1¾	10·229	·8524	4½	67·637	5 636
1⅞	11·743	·9786	5 in.	83·510	6 959
2 in.	13·360	1·113			

Weight of a Lineal Foot of Common Angle Iron, for the construction of Steam Boilers, &c.

Breadth in inches.	Weight in pounds.	Breadth in inches.	Weight in pounds.
3	10·4	2	3·9
2¾	8·3	1¾	3·3
2½	6·5	1½	2·7
2¼	5·0		

TABLE OF THE WEIGHT OF FLAT BAR, HOOP, PLATE, AND SHEET IRON.

Weight of a Lineal Foot of Flat Bar and Hoop Iron in pounds.

Thickness in inches.	Breadth in inches.									
	2½	3	2¾	2½	2¼	2	1¾	1½	1¼	1	¾
⅛	1·47	1·26	1·15	1·05	·094	·084	·073	·063	·052	·042	·031
3-16	2·20	1·89	1·73	1·57	1·41	1·26	1·10	·094	·078	·063	·047
¼	2·94	2·52	2·31	2·10	1·89	1·68	1·47	1·26	1·05	·084	·063
⅜	4·41	3·78	3·46	3·15	2·83	2·52	2·20	1·89	1·57	1·26	·094
½	5·88	5·04	4·62	4·20	3·78	3·36	2·94	2·22	2·10	1·68	1·26
⅝	7·35	6·30	5·77	5·25	4·72	4·20	3·67	3·15	2·62	2·10	1·57
¾	8·82	7·56	6·93	6·30	5·66	5·04	4·41	3·78	3·15	2·52	
⅞	10·29	8·82	8·08	7·35	6·61	5·88	5·14	4.41	3·67	2·94	
1 in.	11·76	10·08	9·24	8·40	7·56	6·72	5·87	5·04	4·20		

Weight of a Square Foot of Plate Iron in pounds.

Thickness in parts of an inch.	⅛	3-16	¼	5-16	⅜	7-16	½	9-16	⅝	11-16	¾
Weight in pounds.	5	7½	10	12½	15	17½	20	22½	25	27½	30

Weight of Square Foot of Sheet Iron in pounds.

Number on wire gauge,	1	2	3	4	5	6	7	8	9	10	11
and weight in pounds.	12·5	12	11	10	9	8	7·5	7	6	5·68	5
Number on wire gauge,	12	13	14	15	16	17	18	19	20	21	22
and weight in pounds.	4·62	4·32	4	3·95	3	2·5	2·18	1·93	1·62	1·5	1·37

Weight of a Square Foot of Sheet and Plate Copper in pounds.

Number on wire gauge,	12	13	14	15	16	17	18	19	20	21	22
and weight in pounds.	5·08	4·34	3·60	3·27	2·90	2·52	2·15	1·97	1·78	1·62	1·45
Thickness in parts of an inch.	5-32	3-16	7-32	¼	9-32	5-16	11-32	⅜	13-32	7-16	½ in.
Weight in pounds.	7·26	8·71	10·16	11·61	13·07	14·52	15·97	17·41	18·87	20·32	23·22

NOTE.—The weight of plate or sheet iron being 1. The weight of brass equals 1·09, and the weight of lead 1·48.

ENGLISH STANDARD MEASURES.

LINEAL MEASURE.

12 inches	= 1 foot.
3 feet	= 1 yard.
1760 yards, or 5280 feet	= 1 statute mile.
7·92 inches	= 1 link.
100 links, or 22 yards	= 1 chain.
80 chains	= 1 statute mile

SQUARE MEASURE.

144 square inches	= 1 square foot.
9 square feet	= 1 square yard.
4840 square yards	= 1 acre.
62·7264 square inches	= 1 square link.
10000 square links	= 1 square chain
10 square chains	= 1 acre.

CUBIC MEASURE.

1728 cubic inches	= 1 cubic foot.
27 cubic feet	= 1 cubic yard.

LIQUID MEASURE.

8·665 cubic inches	= 1 gill.
4 gills	= 1 pint.
2 pints	= 1 quart.
4 quarts, or 277·274 cubic inches	= 1 gallon.

CORN MEASURE.

2 gallons	= 1 peck.
4 pecks, or 2218·192 cubic inches	= 1 bushel.
8 bushels	= 1 quarter.
5 quarters	= 1 load.

AVOIRDUPOIS WEIGHT.

27·34375 troy grains	= 1 drachm.
16 drachms	= 1 ounce.
16 ounces	= 1 pound.
28 pounds	= 1 quarter.
4 quarters, or 112 pounds	= 1 cwt.
20 cwts., or 2240 pounds	= 1 ton.

Common Gravity of Fresh Water.

1 cubic inch	=	·03617 pound
12 cubic inches	=	·434 "
1 cubic foot	=	62·5 pounds.
1·8 cubic feet	=	1 cwt.
35·84 cubic feet	=	1 ton.
1 cylindrical inch	=	·02842 pound
12 " inches	=	·341 "
1 " foot	=	49·1 pounds.
2·282 " feet	=	1 cwt.
45·64 " feet	=	1 ton.
1 cubic foot	=	6·25 imp. galls.
1 cylindrical foot	=	5 imp. gallons.
11·2 imperial gallons	=	1 cwt.
224 " "	=	1 ton.
1 cubic foot of sea-water	=	64·2 pounds.
34·9 cubic feet of do.	=	1 ton.

Approximate Weights for Practical Purposes.

	Specific gravities.	Weight of a cubic inch in pounds.	Weight of a cylindrical inch in pounds.
Iron, cast . .	7207	·2608	·2048
Iron, bar . .	7700	·2785	·2187
Steel	7833	·2833	·2225
Copper . . .	8878	·3211	·2522
Brass, cast . .	8396	·3037	·2385
Zinc, common .	7028	·2542	·1996
Lead	11352	·4106	·3225
Tin, cast . .	7291	·2637	·2071

Table giving the Distance of Terrestrial Objects at Sea.

Height of the eye in feet.	Distance of the object in miles.	Height of the eye in feet.	Distance of the object in miles.	Height of the eye in feet.	Distance of the object in miles.	Height of the eye in feet.	Distance of the object in miles.
1	1·32	20	5·92	39	8·26	90	12·55
2	1·87	21	6·06	40	8·37	95	12·89
3	2·29	22	6·21	41	8·47	100	13·23
4	2·65	23	6·34	42	8·57	105	13·56
5	2·96	24	6·48	43	8·68	110	13·88
6	3·24	25	6·61	44	8·75	115	14·19
7	3·50	26	6·75	45	8·87	120	14·49
8	3·74	27	6·87	46	8·97	125	14·79
9	3·97	28	7·00	47	9·07	130	15·08
10	4·18	29	7·12	48	9·17	135	15·37
11	4·39	30	7·25	49	9·26	140	15·65
12	4·58	31	7·37	50	9·35	145	15·93
13	4·77	32	7·48	55	9·81	150	16·20
14	4·95	33	7·60	60	10·25	160	16·73
15	5·12	34	7·71	65	10·67	170	17·25
16	5·29	35	7·83	70	11·07	180	17·75
17	5·45	36	7·94	75	11·46	190	18·24
18	5·61	37	8·05	80	11·83	200	18·71
19	5·77	38	8·16	85	12·20		

NOTE.—It is ascertained that sound in a temperature of 62° Fahrenheit travels at the rate of 1125 feet per second, and a diminution of temperature equal to 1° Fahrenheit causes an increased velocity of sound equal to 1·14 feet; hence, suppose the flash of a gun from a ship is seen 33 seconds before the report is heard, the distance will be $1125 \times 33 =$ 37,125 feet, or, 12,375 yards between the gun and where the report is heard.

To compare Degrees of Temperature indicated by different Thermometers.

RULE 1.—Multiply degrees of Centigrade by 9 and divide by 5; or multiply degrees of Reaumur by 9 and divide by 4. Add 32 to the quotient in either case, and the sum is degrees of Fahrenheit.

RULE 2.—From degrees of Fahrenheit subtract 32, multiply the remainder by 5, and divide by 9 for degrees of Centigrade; or multiply by 4 and divide by 9 for degrees of Reaumur.

Tables deduced from Experiments on Iron and Copper Plates for Steam Boilers, by the Franklin Institute, Philadelphia.

Iron boiler plate was found to increase in tenacity as its temperature was raised, until it reached a temperature of 550° above the freezing point, at which point its tenacity began to diminish. The following table exhibits the cohesive strength at different temperatures:—

At	32° to 80°	the tenacity was	= 56,000 lbs., or one-seventh below its maximum.
At	570°	" "	= 66,500 lbs., the maximum.
At	720°	" "	= 55,000 lbs., the same nearly as at 32°.
At	1050°	" "	= 32,000 lbs., nearly one-half of the maximum.
At	1240°	" "	= 22,000 lbs., nearly one-third of the maximum.
At	1317°	" "	= 9,000 lbs., nearly one-seventh of the maximum.

At 3000° iron becomes fluid.

NOTE.—The accidental overheating of a boiler was found to reduce its strength from 65,000 pounds to 45,000 per square inch.

Table showing the Diminution of Strength of Copper Boiler Plates by additions to the temperature, the cohesion at 32° being 32,800 pounds per square inch.

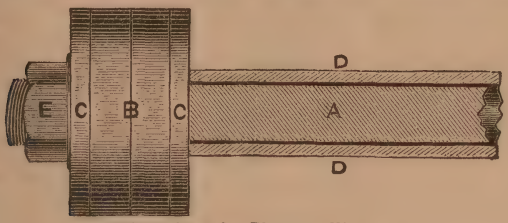
No.	Temperature above 32°.	Diminution of strength.	No.	Temperature above 32°.	Diminution of strength.
1	90°	0·0175	9	660°	0·3425
2	180	0·0540	10	769	0·4398
3	270	0·0926	11	812	0·4944
4	360	0·1513	12	880	0·5581
5	450	0·2046	13	984	0·6691
6	460	0·2133	14	000	0·6741
7	513	0·2446	15	1200	0·8861
8	529	0·2558	16	1300	1·0000

Table of Experiments on Iron Boiler Plate at high temperatures, the mean maximum tenacity being at 550°=65,000 pounds per square inch.

Temperature observed.	Diminution of tenacity observed.	Temperature observed.	Diminution of tenacity observed.
550°	0·0000	824°	0·2010
570	0·0869	932	0·3324
596	0·0899	947	0·3593
600	0·0964	1030	0·4478
630	0·1047	1111	0·5514
652	0·1155	1155	0·6000
722	0·1436	1159	0·6011
732	0·1491	1187	0·6352
734	0·1535	1237	0·6622
766	0·1589	1245	0·6715
770	0·1627	1317	0·7001

BRITTAIN'S TUBE PLUGGER.

This Tube Plugger was invented by Wilson Brittain, chief engineer of the Philadelphia and Reading Co.'s Steamship, *Pottsville*. The sketch shows one end. Each end of the stopper just fills the length of the tube which is leaky.



Brittain's Tube Plugger. Fig. 58.

A is the tube rod which must be of suitable length. B is two rubber washers, generally made from air-pump valve. C is two ¼-inch iron washers, to be rather smaller than the rubber. D represents a piece of wrought-iron pipe, to be made of such a length that when the washers and nuts are on both ends, the washers on the ends will be level with the tube-sheet. E is the nut and washer on the rod. It is always advisable to have half-a-dozen of these at hand, fitted and ready for use, then all there is to do is to push the rod into the tube until the outside washer comes level with the tube-sheet and screw on the nut until the leak stops. Then after a while screw up again solid, and the expansion of the gum from between the washers at each end will make a good job of it.

A practical engineer assures us that he has run with a tube plugged in this way for a month. When you want to remove the plug, slacken the nut and pull the plug out whilst the boiler is hot. In using the plug there is no need of a man going into the back connections, as all is done in the fire-room.

A Pyrometer is an instrument used for measuring extreme degrees of temperature. It is useful to marine engineers in

fixing the temperature of the uptake, connections, flues, etc., where an ordinary thermometer cannot be used. Fig. 59

Bulkley's Pyrometer. Fig. 59.

shows the kind made by Henry W. Bulkley, New York city, which has a standard reputation.

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